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Designing Inhabitant-centered Experiences for Future Smart Homes

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Abstract

Smart homes and home automation technologies are increasingly growing in popularity for end consumers and thereby create an increasingly diverse target group. Many technologies for this space have been developed in research which tackle various technical challenges in enabling smart home visions to automate people's lives. However, those advances have often focused on the technology instead of the user and thus resulted in a large variety of technical solutions that are difficult to integrate well into a person's life. Advances in artificial intelligence and machine learning have started finding their way into domestic lives as well and raise the question of how people will interact with increasingly proactive technologies which can take actions on their behalf.

This dissertation aims to leverage an understanding of existing human needs, practices, and routines in households, to inform the future designs of smart and automated home technologies which will support inhabitants in their daily lives. We first explore and review the landscape of smart homes, in research and industry. We then conduct a systematic analysis of existing work in order to identify trends and challenges in this research space as well as to propose visions for future smart homes that support their inhabitants. To ground this, an empirical study provides insights into the current smart home reality and identifies the various roles of inhabitants and their unique challenges in everyday life. Probing into the design space of current as well as future smart home interactions, this thesis provides three different approaches which address the current problems of smart home inhabitants and explore potential future functionality for improved user experiences within proactive homes.

Zusammenfassung

Smart Home-Technologien und Gebäudeautomation erfreuen sich wachsender Beliebtheit bei Konsumenten, wodurch eine zunehmend vielfältigere Zielgruppe entsteht. Viele solcher Technologien wurden in der Forschung mit dem Ziel entwickelt technische Herausforderungen zu bewältigen und Visionen von Smart Homes zu ermöglichen, in denen das Leben der Menschen automatisiert wird. Oft lag der Fokus dieses Fortschrittes jedoch auf der Technologie statt auf der Unterstützung ihrer Nutzer. Daraus resultierte eine Vielzahl technischer Lösungen, die sich nur schwer ins Alltagsleben integrieren lassen. Fortschritte in künstlicher Intelligenz und im maschinellen Lernen finden ebenfalls langsam ihren Weg ins häusliche Leben und werfen dadurch die Frage auf, wie Menschen mit derartigen steigend proaktiveren Technologien umgehen werden, wenn diese in ihrem Namen handeln können werden.

Diese Dissertation hat zum Ziel das Verständnis von bestehenden menschlichen Bedürfnissen, Gewohnheiten, und Routinen in Haushalten zu nutzen, um zukünftiges Design von smarten und automatisierten Technologien für Privathaushalte so zu beeinflussen, dass es Bewohner in ihrem täglichen Leben unterstützen kann. Zuerst erkunden und besprechen wir den grösseren Kontext von Smart Homes in Forschung und Industrie. Anschliessend führen wir eine systematische Analyse von bestehenden Arbeiten durch, um sowohl momentane Trends und Schwierigkeiten in diesem Forschungsbereich aufzuzeigen, als auch um eine Vision für zukünftige Smart Homes vorzuschlagen, die ihre Einwohner unterstützen können. Um diese Vision mit der Praxis zu verknüpfen, führen wir eine empirische Studie durch, welche Einsichten in die momentane Smart Home-Realität gibt und die die verschiedenen Rollen der Bewohner und ihre alltäglichen Schwierigkeiten darlegt. Um die Designmöglichkeiten für heutige und zukünftige Interaktionen mit Smart Homes zu erforschen, stellt diese Forschungsarbeit drei verschiedene Ansätze vor, die sich sowohl mit den momentanen Problemen der Smart Home Bewohner als auch potentiellen zukünftigen Funktionalitäten befasst, um das Nutzererlebnis mit einem proaktivem Zuhause zu verbessern.

Relevant Publications

Some of work we present in this dissertation, including figures, tables, and text, has partially appeared in the following publications.

Full Papers and Notes

Mennicken, S., & Huang, E. M. (2012). Hacking the natural habitat: an in-the-wild study of smart homes, their development, and the people who live in them. In *Proceedings of Conference on Pervasive Computing (Pervasive '12)*. (Chapter 3)
http://doi.org/10.1007/978-3-642-31205-2_10

Mennicken, S., Vermeulen, J., & Huang, E. M. (2014). From today's augmented houses to tomorrow's smart homes: new directions for home automation research (pp. 105–115). In *Proceedings of the ACM Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '14)*. (Chapter 2)
http://doi.org/10.1145/2632048.2636076

Mennicken, S., Kim, D., & Huang, E.M. (2016). Integrating the Smart Home into the Digital Calendar. In *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI '16)* (Chapter 4)
http://doi.org/10.1145/2858036.2858168

(Note) Ur, B., Pak Yong Ho, M., Brawner, S., Lee, J., **Mennicken, S.**, Picard, N., Schulze, D., & Littman, M., Trigger-Action Programming in the Wild: An Analysis of 200,000 IFTTT Recipes. In *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI '16*).
http://doi.org/10.1145/2858036.2858556

Mennicken, S., Zihler, O., Juldaschewa, F., Molnar, V., Aggeler, D., & Huang, E.M. (2016). "It's like living with a friendly stranger": Perceptions of Personality Traits in a Smart Home. To appear in *Proceedings of the ACM Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '16)*. (Chapter 5)

Posters & Videos

Mennicken, S., Hofer, J., Dey, A. K., & Huang, E. M. (2014). Casalendar: a temporal interface for automated homes. *In Extended Abstracts of the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI '14)* (Section 4.5)
http://doi.org/10.1145/2559206.2581321

Mennicken, S., Brush, A. J. B., Roseway, A., & Scott, J. (2014). Exploring interactive furniture with EmotoCouch. In *Adjunct Proceedings of the ACM Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '14)* (Chapter 6)
http://doi.org/10.1145/2638728.2638846

Workshop Papers

Mennicken, S., & Huang, E. M. (2012). Why Can't I Have Both? The Tension Between Comfort and Control in Smart Homes. Presented at "Pervasive Intelligibility" Workshop *of the Conference on Pervasive Computing (Pervasive '12).* (Section 3.3.4)

Mennicken, S., & Huang, E. M. (2013). Comment Cards, Home Sketches, and Family Personas. Eliciting Experiences with Home Technologies. Presented at *"Studying Technology in the Home" Workshop at the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI '13)* (Section 3.4.1)

Mennicken, S., Brush, A. J. B., Roseway, A., & Scott, J. (2014). Finding roles for interactive furniture in homes with EmotoCouch (pp. 923–930). Presented at *"HomeSys" workshop* and in *Proceedings of the ACM Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '14)* (Chapter 6) http://doi.org/10.1145/2638728.2641547

Workshops

Brush, A. J. B., Scott, J., & **Mennicken, S.** (2013). HomeSys 2013: workshop on design, technology, systems and applications for the home (pp. 765–768). In *Adjunct Proceedings of the ACM Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '13)* http://doi.org/10.1145/2494091.2497329

Mennicken, S., Hwang, A., Yang, R., Hoey, J., Mihailidis, A., & Huang, E. M. (2015). Smart for Life: Designing Smart Home Technologies that Evolve with Users. In *Extended Abstracts of the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI '15)* http://doi.org/10.1145/2702613.2702631

Related Supervised Bachelor/Master Theses

Hofer, J. (2013). Improving the understanding of "smart home" information using temporal metaphors, Bachelor Thesis in the Department of Informatics, University of Zurich (Section 4.5)

Kocovski, F.(2015). Exploring the use of different control and feedback types in a smart home calendar interface. Bachelor Thesis in the Department of Informatics, University of Zurich (Section 4.6.1)

Zihler, O., Juldaschewa, F., Molnar, V., & Aggeler, D. (2015) Integrating Personality Traits in Smart Homes. Master Project Report in the Department of Informatics, University of Zurich (Chapter 5)

Research Acknowledgements

Throughout the thesis, I will use "we" to describe the conducted research as much of the presented work is a result of collaborations of varying degree. In this section I would like to clarify the contributions.

1. **Passive User Study (Section 3.4):** While I conducted all interviews, I had very valuable input from Prof. Anind Dey, CMU on the interview protocols as well as on the analysis. During his sabbatical in 2012, he also coded parts of the data so that we could discuss the outcome with each other.
2. **Casalendar v1 (Chapter 4.5):** Jonas Hofer created the first prototypes for Casalendar within the scope of his bachelor thesis in 2013. He further conducted the early evaluations described in this chapter. The analysis of the interactive prototype was done in collaboration with him.
3. **Casalendar v2 (Chapter 4.6):** Filip Kocovski created the second design iteration of the early Casalendar prototype and collected user data from the participants that were not living in smart homes.
4. **Personality Home (Chapter 5):** The design of the prototype was carried out by Oliver Zihler, Frida Juldaschewa, Veronika Molnar, and David Aggeler during their master project in Summer 2015. I was actively involved in the conception, design decisions, and creation of the study material. While some of the code was based on parts that had already been developed for Casalendar, most of the programming was done by the students.
5. **EmotoCouch (Chapter 6):** The prototype development as well as the studies were conducted while I was an intern at Microsoft Research in the summer of 2013. A.J. Bernheim Brush supervised me as I created the prototype designs and the study material. James Scott supported me in technical questions and Asta Roseway acted in a supervisory role regarding questions of design and affective computing. The study analysis was also conducted in collaboration with them.

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Chapter 1. Introduction

This dissertation analyzes and explores current user experiences with home automation as well as possible future ones, to inform interaction design for the natural progression of smart homes in gaining increasing proactivity. It maps out the existing smart home landscape in research and draws from observations from both "in the wild" homes and industry, in order to provide a rich understanding of the interaction between home and inhabitant. By creating multiple design probes along the lines of identified challenges and opportunities, it expands existing knowledge to inform future designs.

1.1. Motivation

A home is much more than just a building that people live in; it embodies the focal point of a person's domestic affections and is the most personal environment that people shape to meet their personal expectations and needs. The words and proverbs stemming from this term such as "homey," "homely" and "make yourself at home" provide examples where the warm, pleasant feelings of a person's wellbeing and familiarity are associated with that space. There is a growing number of computing technologies originating in workspaces or factory settings that introduce objects into this space which are in direct conflict with those associations. In particular, the notion of automation – substituting human labor with machines – can be an awkward fit in the context of a home.

The interest in automation technologies for the home is increasing nevertheless. A market study in 2009 predicted that by 2012, 1.1 million home automation systems would be purchased in North America and that revenue from such systems would exceed $11.8 billion in 2015 (*ABI Research | Home Automation, Security, and Monitoring*, 2012). A retrospective market analysis showed that in 2012 in the United States alone, 1.5 million systems were sold (*ABI Research | Smart Home*, 2015). This more recent study from 2015 also predicts that global revenues in home automation technologies will hit $34 billion in 2020. Thus, the trend of integrating advanced building technologies into the home, such as

Automation technologies are becoming more widespread.

automatic shades, motion-triggered lights and smart heating systems, is increasing. Companies that have provided technologies for the home for decades, such as telecom or energy providers like Verizon (*Verizon Wireless | Smart Home Automation Products*, 2015) or, more locally, Swisscom (*Swisscom | Smart Living*, 2011), have entered into partnerships with home automation providers to develop new applications for their customers for controlling electrical home appliances via smartphone or web interfaces. This indicates that the market is not only growing, but also opening up for a broader audience.

Control of simple functionalities has become unnecessarily complex.

Building technologies usually provide very basic and standard functionalities. Up until now, the means of controlling them were usually very clear and unambiguous. For example, lights were hardwired to one switch and appliances would be controlled directly on the appliance (see Figure 1-1). In recent years, however, building technologies have become more advanced and complex. The "smart" infrastructures of recent homes, often labeled as "smart homes," now offer a variety of options to control such appliances, such as remote control via a web interface, via a local touch panel interface, using a multipurpose switch, or they can even be automated entirely using sensor input or temporal rules (see Figure 1-2).

The increasing flexibility of controls is meant to offer better adaptability to users' needs and increase their perceived comfort. Yet, we will show in the following chapters how they often lead to confusion and frustration, resulting in a suboptimal user experience which was also found in other studies (Bernheim Brush, Lee, Mahajan, Agarwal, Saroiu, et al., 2011b; Takayama et al., 2012). Handling the growing number and heterogeneity of devices, services, and technologies in smart homes (Bernheim Brush, Lee, Mahajan, Agarwal, Saroiu, et al., 2011b) leads to an increasing challenge in creating easily-graspable, seamless interactions for inhabitants, in addition to the long-standing technical challenges of unifying such systems (W. K. Edwards & Grinter, 2001).

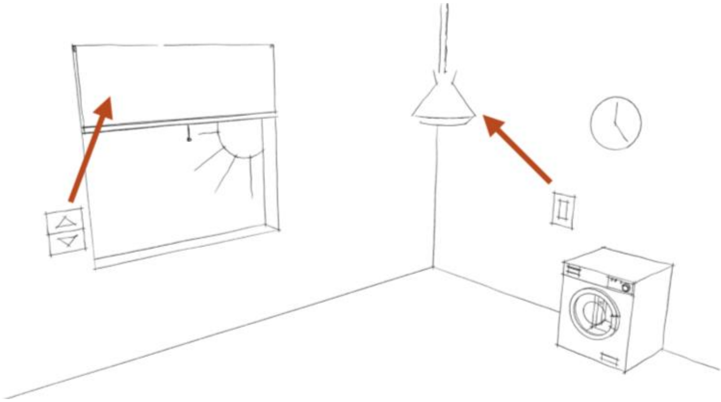

Figure 1-1: Switches are hardwired to certain building technologies; appliances have in-situ controls.

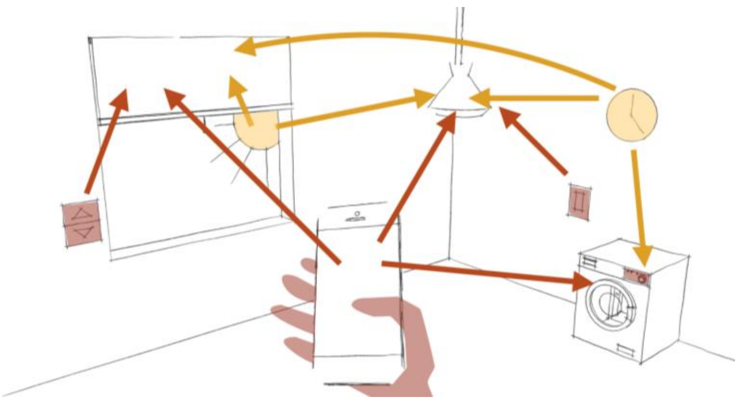

Figure 1-2: Switches can be assigned to various different or multiple functions; building technologies can be remotely controlled using phones or automated (yellow arrows) via rules involving e.g., weather, time, and/or sensor input.

Smart homes have a long-standing research tradition.

In research as well as in industry, the vision of smart homes, homes that cleverly support their inhabitants through technology, has been around for several decades (Aldrich, 2003). Even before Weiser's vision of calm, ubiquitous computing (Weiser, 1999), standards for communication protocols, such as for this specific application area, had already been created and in 1984 the term "smart home" was officially coined by the American Association of House Builders (Figure 1-3). Previous work has regularly discussed whether or how visions of ubiquitous computing – technologies seamlessly interwoven into daily life – have become a reality (Abowd, 2012; Rogers, 2006). It has also been argued that smart homes, as an important area of focus of this vision (W. K. Edwards & Grinter, 2001; Kientz et al., 2008), have become a reality (Yang & Newman, 2013).

Early research has focused on technical feasibility.

The research conducted under the label of "smart homes" has not only been carried out by a variety of disciplines but also looks at the problem space from different angles and with diverse target contributions. Naturally, firstly from a technical point of view, like providing the underlying infrastructure (Rajabzadeh, Manashty, & Jahromi, 2010), providing network communication or developing novel sensors to enable those early visions (see *Infrastructure & network era* and *technical research* in Figure 1-3). Secondly, once the first systems were available and home networking became more widespread in the 90s, research increasingly incorporated socio-technical aspects (see *socio-technical research* in Figure 1-3) and took on a human-centered perspective: investigating family life and coordination, how housework has been carried out so far, where technology is used in the domestic context and in which ways (Elliot, Neustaedter, & Greenberg, 2005; Woodruff, Anderson, Mainwaring, & Aipperspach, 2007a), or providing design implications for smart homes based on such studies (Davidoff, Lee, Yiu, Zimmerman, & Dey, 2006; Röcker, Janse, Portolan, & Streitz, 2004).

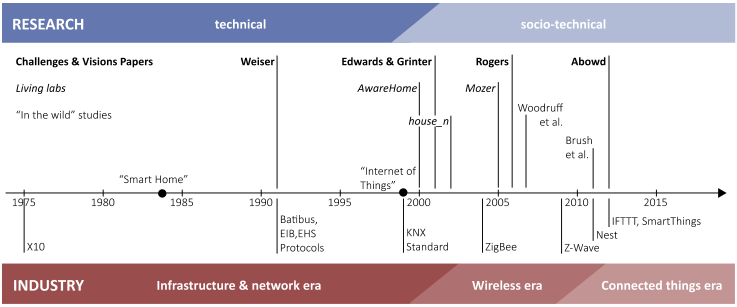

Figure 1-3: Overview about the developing landscape of smart homes in research and industry

Such research has often been conducted in designated spaces simulating actual home environments in lab settings (such as the AwareHome (Kientz et al., 2008) and MIT's house_n (Intille, 2002)). It is an advantage of such projects that they have the ability to develop new technologies while still having easy access to involved components, in order to make functionality modifications and adjustments. However, while lab studies like these are necessary and very valuable for learning about reliability and usability of new technology or user interfaces, they can only provide limited insight into the actual everyday benefits (Rogers, Sharp, & Preece, 2011).

So far, research has mostly been conducted in lab environments.

Only within the last few years has commercial home automation become more available to a broader audience, providing researchers with the opportunity to study how such technology is integrated "in the wild" and what effect it has on home inhabitants. As it is now possible to find study participants who have lived in such homes for a while, researchers have the chance to learn from their hands-on experience to explore potential benefits and discover pitfalls, in order to improve the smart home user experience. This offers the advantage of not having to isolate the technologies from their context and the routines they are intended to support.

Recent availability of commercial solutions affords studying them in the wild.

Current smart homes only have enhanced means of controlling or configuring mundane and traditional building technologies or appliances. In research as well as in popular media, there is often a much more futuristic understanding of what such a home entails. There might be robots helping people with their chores (Cakmak & Takayama, 2013) or cooking meals for of with them (Sugiura, Sakamoto, Withana, Inami, & Igarashi, 2010), drones delivering the mail (*Swiss Post*, 2015), and in their garages might be cars that drive their passengers to their desired destination autonomously. Tesla's software update which enables a self-driving mode in their cars (*Tesla Motors*, 2015) is an example of a similar progression towards the increasing autonomy of technologies. Due to this increasing adoption of machine-learning functionalities in technology, which we will describe more in Section 2.3.3, the home will also be increasingly able to act autonomously. Given this progression from user-defined rules for automation, to an ability to behave proactively, as well as the increased number of involved connected devices and services within and outside of the home, in the future we might not only live *in*, but also *with* our homes. Eventually, homes themselves might take a more active role in people's lives and routines and even express their own "thinking."

Homes will take on a more active role in the future.

Visions of future smart environments often propose interactions with some form of ambient intelligence that simplifies dealing with a complex network of automated devices and makes interactions with visual user interfaces become superfluous. New questions arise: how will people deal with such systems in their own home? What challenges that will occur? How could they be addressed through careful interaction design? Besides looking at the current smart home "reality," our goal is to also explore the context of smart homes in the light of this new set of questions, in order to inform the design of future smart home user experiences and make sure that homes remain places where inhabitants can "feel at home."

New technical contributions have opened a new set of questions for the smart home user experience.

1.2. Goals and Contributions

The overarching research goal is to provide insights from our work that can improve user experiences for inhabitants of current smart homes and inform future smart home research. We intend to explore the potential impacts of new technologies and interactions, using informed design probes we have created, to learn about the effects of increasingly proactive homes on their inhabitants. Our designs are grounded on existing work in this area of research that we carefully synthesize, as well as our observations of current practices and issues in inhabited smart homes. We aim to both extend the research community's understanding of inhabitants' interaction with smart homes, and to show how this can be applied in our design probes. Our goals are summarized in the following thesis statement:

By analyzing existing work in smart home research, empirically studying current smart home experiences in context and creating design probes for potential future smart home experiences, we identify and discuss promising directions for research and offer guidelines for designing user experiences of increasingly proactive smart homes that better support inhabitants and integrate into their routines.

This research is situated in the context of human-computer interaction and pervasive and ubiquitous computing. We identified several open problems and derived a couple of research questions relevant to those areas to guide our work:

Problem 1: **Evolution** of a "Smart" Home

Ideally, smart home technologies support people in their everyday life throughout their entire life-course. Given the rapid cycles of technical innovations in this active space of research, people will adopt, reject, and adapt to such technologies multiple times in their life. But current smart home research usually focuses on the immediate user interactions with the technologies themselves and only once they have been installed. Thus, we do not have a good understanding of how people adopt such technologies, which is crucial for informing the suitable design and development of future smart homes.

Research Question: How does a smart home develop "in the wild"? How does it get adapted to the inhabitants' everyday lives and how do inhabitants themselves adapt to it? What are the challenges of the process?

Problem 2: **Multiple-user Interaction** in a Smart Home

Technologies and appliances in the home should be easy to use for all family members and while domestic environments are often multi-user environments, many technologies are designed for a single-target user group. This might put certain user groups at a disadvantage or result in dependencies between people sharing a household. Currently, we lack an understanding of what the specific user needs are for smart home technologies for each of the various people sharing a home, something which is needed to create accessible systems.

Research Question: What roles do inhabitants take on and what are their individual challenges when interacting with a smart home?

Problem 3: **Intelligibility** of Smart Home Behavior

Due to the myriad of different devices in domestic environments as well as their increasing connectedness and the automated behaviors they can display, smart home technologies can easily become complex and thus, no longer transparent. However, in order to help inhabitants get value out of the data their homes collect and to understand its behavior, we need to improve existing interfaces for interactions with the smart home.

Research Question: How can we increase intelligibility of mixed-initiative technologies, by visualizing their effects using familiar metaphors and by taking into account inhabitants' existing knowledge and routines?

Problem 4: **Agency** of Smart Homes

New smart home products are increasingly incorporating advances from machine learning, voice interaction and agent interfaces. However, there's a lack of understanding of how these advances can be used advantageously, in the context of what people's perceptions are when the home can act as an agent on their behalf, or even interact in a conversational manner. This leads to a series of open questions worth answering that are related to the nature of the characteristics an agent borrows from human interactions and the degree to which they are beneficial.

Research Question: How do inhabitants react when including human-like characteristics in interactions with a home? What are the beneficial use cases for them to support user experiences?

The following contributions arise from our analysis of literature, our studies of practice, and the design and deployment of novel technologies as probes:

1. An identification of promising research directions and an updated vision of future smart home experiences (Chapter 2), derived from a formal literature review, which provides a comprehensive overview of the current smart home research landscape.
2. An in-depth exploration of smart homes "in the wild" and their inhabitants (Chapter 3), to provide an understanding of smart homes in context.
   - In this exploration we provide a phase-based model of smart home development to answer our research question of how a smart home develops "in the wild" and becomes adapted to the inhabitants' everyday life (Section 3.3.3).
   - Besides looking at the home, we also present a set of roles, including their characteristics and challenges, to describe what

methods of engagement different inhabitants take on and what their individual challenges are when interacting with a smart home (Section 3.3.4).
    - Our insights from the wild allowed us to derive a set of directions for promising research avenues (Section 3.6).
3. To evaluate our goal of a better integration of people's routines and technologies, we conducted **a case study in the wild (Section 4.7)** testing our calendar interface concept Casalendar in actual homes. We address the question of **how intelligibility of mixed-initiative technologies can be increased by visualizing their effects, using an example of a temporal metaphor, a calendar.** This chapter provides an application and testing of theoretical design guidelines and how they add to the small body of "in the wild" deployment of smart home prototypes. Based on the results, we discuss our findings and the **design implications for smart home interfaces (Section 4.7.5).**
4. To complement the implications for current smart home interfaces with the implications for increasingly proactive smart home interfaces we used provocative prototypes in lab studies to also identify **research avenues for proactive smart home agent interfaces (Chapter 5 and Chapter 6).** In these chapters we investigate how people react to the concept of a home that is more proactive, the attitude towards anthropomorphized interfaces, and how human-like communication characteristics could be used for smart home technologies.
5. The adoption of multiple technologies for our "in the wild" as well as our lab studies, provides a more practical contribution: a set of **methods for studying people's attitudes** towards their homes which we will report on throughout our work in the respective chapters.

In this dissertation we include interactions with multiple technologies that have their own field of research, such as machine learning, activity recognition, robotics and calendaring. While the focus of our work was to extend and deepen the understanding of the user experience when interacting with these, we found through discussions with a large variety of other researchers that it also raises questions and challenges within those research fields. When discussing such crosscutting themes in this thesis we do not attempt to answer them, but to provide researchers of the respective areas with helpful information, putting it in the context of the user.

1.3. Approach and Methods

For this dissertation, we took a multifaceted approach to identify ways to improve the user experience in smart homes, to better integrate people's routines and domestic technologies, and to deepen our understanding about existing as well as future smart homes. The majority of our work uses qualitative methods which are common practice in the human-computer interaction communities, but less so in other areas of computer science. We chose them purposely as those methods allow us to investigate and reveal unknown aspects of smart homes in the wild, and people's attitudes towards future user experiences as well as underlying reasons for them. Our goal was to learn about the broad range of influences, how they connect with each other, and which questions they raise.

We conducted a structured literature review combining it with observations in industry to identify emerging themes and interests.
To be able to build on the body of work conducted in this space, as well as addressing current trends in industry, we conducted a structured literature review (Chapter 2). It allowed us to identify future upcoming challenges as well as which findings exist that could support us in addressing the challenges identified in our fieldwork. By matching existing challenges and emerging themes in related work in this space, we identified two aspects that we decided to investigate and study further: a) the disconnect between people's routines and the technologies in their homes and b) people's perception of proactive and social behavior in homes.

We took advantage of the recent opportunity to study smart home technologies and their users, the inhabitants, in the natural habitat: their homes, to learn about existing challenges and interactions with such technologies.

Our work started with an exploratory home tour study to understand smart home technologies in context (Chapter 3). By interviewing not only inhabitants of such homes but also other stakeholders involved in the process of making a home "smart," we were able to gain a broad understanding of the user experience and identify several opportunities to improve it as well as potential ways to do so. We conducted exploratory qualitative interviews with three groups of stakeholders: 1) inhabitants of homes equipped with automation technology, 2) people being in the process of planning or building automated homes, and 3) providers of commercial solutions for home automation. The objective of this study was to understand how a smart home develops starting with a person's initial idea of instrumenting their home with automation technologies to their experiences when living with them. Our study comprised semi-structured interviews with a total of 22 participants (10 smart home inhabitants in 7 households, 5 people in 3 households currently in the process of planning or building a smart home, and 7 professionals) and home tours of 6 of the inhabitants' homes. We analyzed the data using a grounded theory-based affinity analysis (Beyer & Holtzblatt, 1999).

We built up on the gathered knowledge and understanding of the context and created probes to learn about potential future interactions:

- *We developed and prototyped a concept to improve current smart home interactions.*
  To find ways to better connect people's routines and technologies in the home, we took inspiration from the way people capture and manage their routines and created a calendar which integrates the smart home which we studied in the lab as well as in an "in the wild" deployment (Chapter 4).
- *We created provocative prototypes that we studied in our labs to learn about the future vision of agent-like homes.*
  To learn more about people's perceptions of proactive and

social behavior in homes, we looked deeper into the notion of agency of a smart home and the consequent associations of human-like interactions in inhabitants (Chapter 5 and Chapter 6). We created two provocative prototypes to elicit responses in study participants which allowed us to assess their attitudes and potential beneficial use cases.

1.4. Organizational Structure

This dissertation contains two parts: the first part focuses on the work we carried out to build up a rich understanding of the context. The second part describes the interaction concepts and the probes we developed based on that understanding and the insights from our evaluation of them.

We begin **Part 1: "Understanding the Context"** by briefly discussing the term "smart home" to provide a clearer scope for this work. In **Chapter 2** we then map out the smart home landscape, in research as well as in industry, and present three themes of existing and current challenges: creating meaningful technologies, designing for complex domestic spaces, and problems within human-home collaboration. This overview is complemented by our efforts to understand the context and the user's perception of smart home technologies in **Chapter 3.** We describe people's understanding of the term "smart" in this context, their motivations for getting such technologies, the different roles they take on when living in such a home, phases of how the home develops and the challenges that occur within them.

In **Part 2: "Probing Different Interaction Approaches"** we present our approaches for addressing identified challenges and to probe on potential future interactions with smart homes. In **Chapter 4** we present our interaction concept, to integrate management of people's routines and domestic technologies more thoroughly. We report on the details of the interface design of our calendar interface Casalendar, how we evaluated it in a case study which was deployed in two smart homes, the findings from that study and the implications they have. In **Chapter 5 and Chapter 6** we lay out our research efforts to investigate the space of smart home agent interfaces and the associated anthropomorphism, to learn about users' perception of agency in such homes. We describe our prototype, how we evaluated it to elicit responses from our participants, and the implications of our findings.

In **Chapter 7** we summarize our work and contributions. Here we also address the limitations of our work and articulate open questions for future work.

Part I: Understanding the Context

Scoping the Term "Smart Home"

Research in the field of controlling and automating a home or equipping it with novel technologies is often labeled by many names other than just “smart home,” such as “wired home,” “connected home” (Harper, 2011), “automated home,” “smart living environment” and more. As people’s expectations of what such technology can do for them are changing, the vision of what a “smart home” entails continuously evolves as well. Nowadays, many people call a home “smart” that can be remotely accessed to turn devices on and off, even though there is in fact no actual automation involved. From a technical point of view, researchers in this field might only call homes “smart” when they are responsive to their inhabitants and adapt autonomously in sophisticated ways, e.g., using intelligent machine learning algorithms to predict user occupancy and control the heating system (Scott et al., 2011). The socio-technical perspective also includes people’s goals in the notion of “smart,” e.g. home automation having to “satisfy domestic needs” (Takayama et al., 2012) or a relative comparison to one’s own capabilities: “it’s not smart if I can do it better,” which we found in our own empirical work and will discuss more in Section 3.3.1 (The Understandings of "Smart"). In industry, “smart” is often used simply as a marketing term to describe programmable technologies in general or devices that can perform some sort of action automatically.

To scope the focus of this work more pragmatically and situate it within ubiquitous computing research, we defined two minimum requirements of what a home needs to offer in terms of functionality to be “smart” for our participant recruiting:

- A smart home can sense the state of the home and activities in and around it (for example, by using motion/brightness sensors, or by monitoring internet usage or electricity consumption).
- A smart home can perform certain actions automatically using sensors and predefined rules (for example, actuating shades, lights, heating, but also providing notifications or alerts to occupants).

Chapter 2. Landscape and Industry Trends[1]

As introduced in the motivation for this dissertation, a considerable amount of research has been carried out to make long-standing smart home visions technically feasible. There are decades of research – in academia and in industry – as well as numerous commercially available solutions in this space that make for a large and complex body of work to consider. Additionally, this area's boundaries are inherently fuzzy as even with our previously introduced definition, the term "smart home" is not precisely confined to specific settings, applications, devices, or technical capabilities. This chapter intends to provide an overview over the smart home research landscape and current work and trends in industry. We synthesize this broad body of research with observations from industry and experiences from our own empirical work to provide a discussion of ongoing and emerging challenges, namely challenges for *Meaningful Technologies, Complex Domestic Spaces*, and *Human-Home Collaboration*. Within each of these three challenges we discuss our visions for future smart homes and identify promising directions for the field.

While this chapter also provides readers with a general background and related work in the context of this dissertation, it was originally conceived as a survey of the entire field of smart home research. As such, it goes beyond providing the background for the research questions which will be addressed in this dissertation. Therefore, many of the challenges and research directions we present are out of the scope of this thesis. We will describe which ones we pursued further at the end of the chapter. To provide more specific background for each chapter's focus, all following chapters will contain their own background sections.

[1] Based on: **Mennicken, S**., Vermeulen, J., & Huang, E. M. (2014). From today's augmented houses to tomorrow's smart homes: new directions for home automation research (pp. 105–115). In *Proceedings of the ACM Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '14).*

2.1. Background

Long-standing tradition of smart home research, but new challenges emerged.

As the research landscape of smart homes is quite diverse, identifying underdeveloped areas and aggregating findings and lessons learned within the various involved disciplines is an existing problem. Several previously defined challenges, such as providing a means to connect different devices (W. K. Edwards & Grinter, 2001), have already been addressed to some extent or could feasibly be addressed from a technical point of view. New technologies have also introduced new challenges. For example, there is the increasing difficulty of maintaining and securing home networks due to the invisibility of connections introduced by wireless networks, and the increasing complexity of installations due to a larger quantity of devices.

Research had to overcome technical challenges first.

The majority of research in the early years of ubiquitous computing in general – and smart homes in particular – was focused on addressing technical challenges in order to realize the ubiquitous computing vision of technologies that would *"weave themselves into the everyday life until they are indistinguishable from it"* (Weiser, 1999). Several of those fundamental challenges have been addressed in the area of smart home research, for example, providing basic sensing infrastructure or a means to actuate home appliances. Many other challenges regarding underlying technologies have been identified and described. One key example that provided an overview of these challenges is the seminal work by Edwards and Grinter (W. K. Edwards & Grinter, 2001) in which they offer detailed insights on technical challenges, such as allowing for the incremental addition of technologies, issues of interoperability, reliability of domestic technologies, and ambiguity in sensing. In addition, they discuss the socio-technical repercussions of these challenges, such as low adoption of such technologies due to inhabitants' lack of technical knowledge or the difficulty of predicting social implications. By doing so they increased the awareness for such challenges and initiated the phase of socio-technical focus for ubiquitous technologies at home (see Figure 2-1). Other work (Frohlich & Kraut, 2003) focused more strongly on the sociological perspective of smart homes to identify the challenges of general computing technologies in the home from inhabitants' perspectives. Ambient assisted living is a noticeable area of application for smart home technologies. While several of the challenges identified in the specific context of this field, such as legal issues or ethical issues (Chan, Estève, Escriba, & Campo, 2008), might not be as urgent for smart homes as for a more general population, other challenges, such as reliability of sensing systems or cost-effectiveness (Chan et al., 2008) remain just as important.

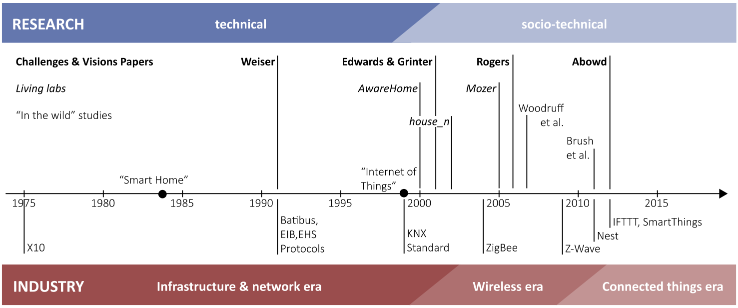

Figure 2-1: Developments of efforts in smart home research and industry

Living lab initiatives such as the Aware Home (Kientz et al., 2008) and MIT's house_n (Intille, 2002) facilitated the study of smart home technologies in more depth and in contexts that closely resemble real world domestic spaces. Mozer's approach of installing various sensing and actuating technologies in his own home to build Adaptive House (Mozer, 2005) was another way of attempting to study actual user experiences of living with automation technologies. All these efforts focused further on people's direct interaction with the technologies and allowed for the exploration of numerous prototypes for novel ideas in the context of technologies in domestic spaces.

In addition to research, smart homes can now also be found "in the wild."

Due to the scarcity of smart home households a decade ago, there was very little research that studied the inhabitants of such homes. But as smart and technology-augmented homes are now emerging "in the wild," there is a new body of knowledge from which we can draw insights and upon which to build. There are varied efforts to gain understanding, ranging from scientific approaches in academia to research and development in industry. The excellent synthesis of challenges for smart home research by Edwards and Grinter (W. K.

The adoption of smart home technologies allows the studying of updated challenges.

Edwards & Grinter, 2001) was presented almost fifteen years ago. While these challenges are still relevant for the field, in many cases they have evolved in terms of technical feasibility and people's expectations as a result of the adoption of new technologies. Brush et al.'s (Bernheim Brush, Lee, Mahajan, Agarwal, Saroiu, et al., 2011b) paper is a great example of the first "in the wild" studies to focus on family homes: their studies of early smart home adopters provides us with a better understanding of what challenges and barriers result from transferring research to practice. The work we discuss in Chapter 3 adds to and extends the understanding provided by them, by looking further at the adoption of such technologies. The research presented in this chapter aims to connect synthesized research insights in literature with the challenges identified "in the wild" to further provide relevant promising approaches and facilitate the creation of useful solutions in the context of home automation.

In this chapter, we provide a synthesis of current challenges and promising directions for smart home research based on an extensive literature review, an analysis of current smart home solutions, and our own field studies of deployed smart home technologies. First, we describe how we surveyed existing research emphasizing the effects on inhabitants' user experience. Then we describe and discuss the challenges as well as our visions for three high-level themes we have identified for smart home research, namely for creating meaningful technologies, addressing the complexity of domestic spaces, and fostering human-home collaboration. For each of these themes, we discuss the aspects that make them challenging, describe our vision of how future smart homes should address them and map out a set of research directions to guide the design of future smart home user experiences and technologies for the domestic context.

2.2. Method

The insights we draw in this work result from a synthesis of several research activities. We conducted a formal literature review specifically to identify user experience-centered challenges in the smart home research landscape. We also drew insights from our research activities investigating smart homes, including empirical field studies and interviews with smart home inhabitants, interviews with and observations of industry professionals, and surveys of current commercial smart home products which we will describe in detail in Chapter 3.

2.2.1. Literature Review

To identify themes within related work, we first assembled a list of work known to the researchers and added any of the 50 top search results in the ACM Digital Library for "home automation" and "smart home" not already included in the known body of work, resulting in a list of 131 papers, posters, and reports. To address our intended focus on the user experience, we then systematically filtered the literature set in order to extract papers that explicitly address the user experience to some extent. To achieve this, we reviewed the abstracts of the work on that list and sorted them into different categories of relevance:

- Focus on automation or building technologies in **domestic spaces** including a discussion of **end user experiences** (35 results)
- Focus on automation or building technologies in **domestic spaces**, but no discussion of end user experiences (12 results)
- Related to automation technologies in buildings, but **no discussion of end user experiences or domestic spaces** (84 results).

While technical contributions in the area of smart homes have been crucial to the advances of this field, our focus was to identify new insights specifically for the user experience in the smart home. In order to focus on the insights and explanations of the researchers whose work we reviewed rather than imposing our own, we excluded the third category. In many cases this was work that solely focuses on providing technical innovations, such as sensor hardware, middleware, communication protocols, or contributions to the field of electrical engineering. Therefore, we reviewed the resulting set of 47 papers, consisting of the first two categories, in greater depth. From these papers, we extracted the parts specifically relevant to user experience for further content analysis.

The relevant parts selected for further analysis focused mostly on (a) understanding and intelligibility of smart homes (Bellotti & Edwards, 2001), (b) means for controlling smart home technologies, or (c) potential social effects on users. We also included sections that addressed other issues pertaining to user experience that we felt were relevant for the analysis. Then we analyzed our data using the affinity diagramming method (Beyer & Holtzblatt, 1999) (see Figure 2-2 (left)) deriving themes that emerged when iteratively clustering the excerpts (see Figure 2-2 (right) for an example). We started by analyzing how different work addressed aspects (a), (b), or (c). Then, to derive recurring themes or tensions to put them into the broader, overarching context of user experience in a smart home, we iterated our analysis of the insights across these aspects.

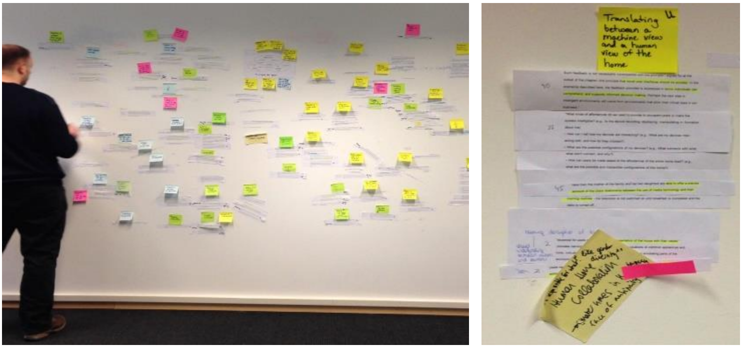

Figure 2-2: (Left) Affinity Diagramming activity to identify emerging themes in related work; (right) example of an affinity group ("Translating between a machine view and a human view of the home") which is part of the high-level theme "Human-Home Collaboration"

Subsequent to our formal analysis of selected literature, we were also made aware of additional relevant related work through informal discussion with other members of the research community. When applicable, we have synthesized insights from these additional works into the analysis we present in this chapter.

2.2.2. Empirical Work

We took a comprehensive and multi-faceted perspective on the field and are drawing data for our analysis from various sources in research, industry, and practice. The findings presented in this chapter are not only derived from a literature review but are also combined with the authors' cumulative research activities in the realm of smart homes, including:

- A semi-structured interview study with 22 participants (10 inhabitants in 7 households living in smart homes, 5 people in 3 households who were in the process of planning or building a smart home, and 7 smart home solution-providers from industry) as well as home tours to six of the smart home inhabitants' homes. The results of this work will be discussed in Section 3.2.
- A mixed-methods study with five people without technical backgrounds who live in smart homes. The focus was to understand everyday interactions, capturing positive and negative aspects of living with automation technologies. The methods used in this study will be discussed further in Section 3.4.
- Observations of two smart home interest group meetings, including presentations of new products. In the first meeting the author of this thesis presented and discussed research results from the previously-mentioned studies with the smart home inhabitants who make up the interest group (see Figure 2-3 (left)). In a second meeting she attended presentations of new smart home products coming out of industry.
- Two visits to different smart home construction sites guided by a smart home provider (see Figure 2-3 (right)). Data was collected using contextual inquiry and participatory

observation methods in order to develop an understanding of practitioners' everyday problems and to discuss their contrast with approaches in research.

By incorporating our own empirical work, we aim to provide a set of directions for moving smart home research forward that is closely connected to the current smart home reality.

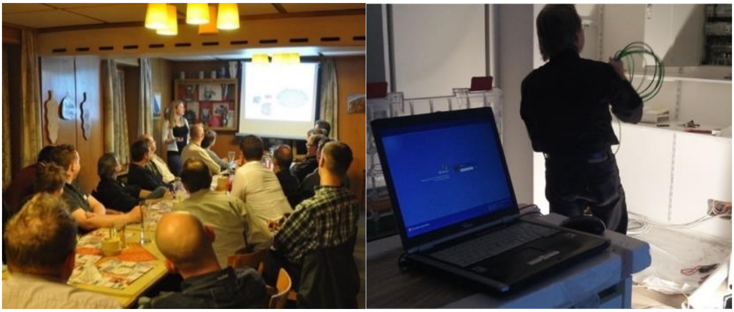

Figure 2-3: (Left) Presenting findings from our empirical work to a smart home interest group; (right) observing the work of a smart home professional on-site

2.3. Findings

The next three sections provide an overview about related work in academia and industry by discussing insights and findings emerging from our collected data along three high-level themes (see Table 2-1): *Meaningful Technologies, Complex Domestic Spaces,* and *Human-Home Collaboration*. While we discuss them individually, these themes are all highly interconnected. Within each of these themes we discuss the specific aspects that emerged as most critical in our analysis, why they pose or continue to pose challenges for research, our visions for smart homes that overcome these challenges to provide better inhabitant experiences, and actionable directions for research that we believe have promise towards fulfilling these visions.

Table 2-1: Overview about the identified themes, changes for the challenges in research, and our visions for future smart homes

Past Challenges	**Current Challenges**	**Visions**
Technical feasibility and interoperability	Meaningful technologies	Future smart homes will support inhabitants' *goals and values.*
Complex domestic spaces	Increasing complexity due to more users, more devices, more modalities	Future smart homes will help to identify *opportunities for automation.*
End-user configuration of sensors and actuators	Understanding machine learning and interacting with artificial intelligence	Future smart homes will *collaborate* with their inhabitants.

2.3.1. Meaningful Technologies

Technological innovation is often still driven by a strong interest in providing a novel contribution and making advances within a specific field of technical research. This kind of systems-oriented research is indispensable for advancing the field of smart homes as it allows researchers who focus on applications to have access to more tools to realize their concepts. However, systems or tools that have been developed with a focus on pushing the boundaries of certain technologies can also introduce the risk of shaping the visions for future applications in a limiting or restrictive way.

Interest in Social Values and High-level Goals

As argued by Taylor et al. (Taylor et al., 2007), technology is to be understood less as something intelligent, but more as a resource for intelligence, in which intelligence emerges through our interactions with technology. Similarly, Rogers argues for more engaging technology which "enables people to do what they want, need or never even considered before by acting in and upon the environment" (Rogers, 2006). We therefore argue that an important consideration for advancing smart homes lies in supporting the goals and values of inhabitants.

In the review of related research we found that people are strongly interested in their own activities and the effects of their behavior in the home (Lynggaard, Petersen, & Hepworth, 2012), often in order to assess their efforts towards achieving a specific goal, e.g., reducing energy consumption (Bartram, Rodgers, & Woodbury, 2011) or "optimizing their own resource use" (Dixon, Mahajan, & Agarwal, 2010). In other cases, they wanted to learn more about the home and the dynamics within it in order to reflect upon the way they live. Related work has identified peoples' interest in "feeling like good parents" (M. K. Lee, Davidoff, Zimmerman, & Dey, 2008) and suggests that smart homes could "participate in the construction of family identity" (Davidoff et al., 2006). Other work poses the question of "how technology physically embodied in the home might support lifestyles such as green living, slow living, or spirituality" (Woodruff, Augustin, & Foucault, 2007b) indicating an existing lack of support for such values. Additionally, each household has its own personal and dynamic set of values embedded into its members' routines. At times efficiency might be important while other times playfulness or other hedonic qualities might be prioritized (Bell & Kaye, 2002).

People are interested to learn more about their homes and themselves.

A major motivation for acquiring home automation is the interest in achieving "peace of mind" (Bernheim Brush, Lee, Mahajan, Agarwal, Saroiu, et al., 2011b) or an interest in feeling connected to one's home (Takayama et al., 2012). These motivations have resulted in security-oriented solutions for the home (Dixon et al., 2010) and suggest technologies that are "readily introspectable" with regard to the user's skills (Takayama et al., 2012). This strong desire to achieve peace of mind with respect to one's home is not only evident in the fact that there was an early emphasis within industry on developing solutions for a building's security, but also in inhabitants' stated desire to know that the things one cares about in the home are safe. Recent industry efforts, such as *Mother* by *sen.se* (*Sen.se | Mother*, 2015), or *Wally* (*Wally*, 2015) – which allow people to use one or more sensors to monitor their home environments – are intended to address this desire and are indicative of the interest of the market.

"Peace of mind" is a major interest.

The Catch of Technological Advances

At the same time, however, homes augmented with technologies intended to provide peace of mind, for example, through remote connection via smart phones and Internet-connected devices, can also introduce perceived and actual threats to privacy and security. This creates a conflict between the goal the technologies intend to support and the side-effects they introduce.

The increased connectedness of our homes (Harper, 2011) can raise questions about what data is being collected, whether it is transferred outside of the domestic environment, and how it is being accessed (Ur, Jung, & Schechter, 2013). As reported by Chetty et al. (Chetty, Sung, & Grinter, 2007), users were often not aware that their homes were accessible to others beyond their physical boundaries through wireless or remote access. Data leaks from sensed data in the home could potentially be very sensitive and might allow for serious abuse, e.g., household rhythms that expose appropriate times to rob a home (Chetty et al., 2007) or means of access control (Ur et al., 2013) which could be hacked by others to turn off the lights, as a relatively harmless example (*Nitesh Dhanjani | Hacking Lightbulbs*, 2015), or potentially for purposes with more malicious intent and worse implications. These scenarios would actually lead to the opposite of the intended goal.

Increased connectedness leads to questions of how data is confined.

These types of negative effects on complex environments with multiple inhabitants are hard to predict, and research efforts often focus on specific topics, rather than considering the home environment as a whole. Such smart home research typically focuses on specific areas of household applications such as cooking, or communication, support for the elderly or disabled, or on specific underlying technologies such as occupancy sensing, activity recognition or location tracking. As a result of this deep but narrow focus within the individual research efforts, technologies are often studied in a rather isolated manner, focusing on their impact on the immediate context of use. Even if they are deployed into actual households, effects on the larger context of the household and whether inhabitants' larger goals and values are being supported have rarely been studied.

Effects on the larger context of a household are difficult to study.

Design needs to balance multiple, potentially conflicting, goals.

Our review and our empirical work also indicated that people often worry about more philosophical issues, such as whether smart homes might make them lazy. Stringer et al. (Stringer, Fitzpatrick, & Harris, 2006) suggest that we need to design "technology [that] should require human effort in ways that keep life as mentally and physically challenging as possible as people age." There is a very delicate balance between enabling goals such as "comfort" and "convenience" without crossing the boundary of making inhabitants feel "lazy." This balance is incredibly difficult to meet, especially given the fact that households are often inhabited by multiple people, each with different values, needs, and roles. Learning about these aspects is one of the research questions which we set out to answer and which we will discuss in more depth in Chapter 3.

Vision: Smart Homes Will Support Lifestyle Choices

We envision that an ideal smart home will support its inhabitants in living the lifestyles they choose while still being able to cope with "irrational" exceptions from them. Instead of "rationalizing" the life of inhabitants, smart homes should contribute to inhabitants' lives by adding meaning and supporting their unique values. Research on smart home technologies or automation technologies in the domestic context therefore needs to put a stronger focus on whether it is in line with the intended users' social values and high-level goals. Many questions remain unanswered that need to be addressed in order for smart homes to support those lifestyle choices:

- What kind of high-level goals do people even have?
- How are these manifested in domestic spaces and how are current technologies involved already?
- Are there ways for researchers to learn how goals can be mapped onto available technologies in order to create solutions that address such a vision?
- If researchers are able to target their efforts to address high-level goals, will it be possible to know whether new technologies to support these goals will be successful when deployed "in the wild"?
- Can we find ways to predict, model, and possibly even deter potential negative side effects on domestic life?

Not only do researchers have to find ways to predict technical conflicts resulting from different configurations of systems, we also need to find ways to predict social conflicts that may arise from attempting to support multiple high-level goals. Conflicting values within a household also need to be considered, for example if parents want to live in a more energy-conscious fashion while their children simply want a maximum level of comfort. Although these types of conflicts already exist in conventional households, smart technology intended to support goals and values adds a new level of socio-technical complexity that needs to be addressed.

Implication: Learn In and From "The Wild"

Confirming the approach that we took for our own work, one key approach towards the vision of a smart home that is emerging in research to support inhabitants' high-level goals, entails putting a stronger emphasis on studying technology "in the wild" and taking advantage of knowledge that we can distill from observations of developments in industry.

Studying technology in a representative context of use will be crucial to assessing its suitability for everyday use and whether or not it addresses inhabitants' intended goals. By grounding designs in reality, researchers might be able to "at least predict the effects of [their] technologies" (W. K. Edwards & Grinter, 2001). As smart home technologies have to deal with interference from other technologies and react to non-standard situations, it is difficult if not impossible to evaluate them through laboratory studies. However, lab studies so far have been the dominant method of assessing smart home technology (Bernheim Brush, Lee, Mahajan, Agarwal, Saroiu, et al., 2011b). Recently, developments such as the Lab of Things (*Microsoft Research | Lab of Things*, 2015) have helped make it feasible to conduct studies "in the wild." Other initiatives by researchers, such as workshops on methods to study technologies in the home (Coughlan et al., 2013) indicate an emerging need for further methods to tackle this complex problem.

Evaluating designs in context can better assess their suitability.

The consumer electronics market for automation technologies is expanding quickly (*BSRIA | Smart Home Market Study*, 2012) and offers us an opportunity to observe what types of products actually address

Consumer products give insights about existing needs.

people's real world needs. There are an increasing number of solutions developed by telecom providers, media companies, dedicated startups, as well as an emerging set of crowd-funded smart home projects. They provide the opportunity to study differences between prototypes coming out of research and products that are backed by the support or votes of the intended target audience.

Combining scenarios with deployable prototypes can help with testing more futuristic ideas.

The aforementioned suggestions focus on the identification of high-level goals. However, research prototypes are often by nature exaggeratedly forward-looking, developed for futuristic scenarios rather than the current reality. Such technologies therefore cannot be studied in the wild, because "the wild" simply does not reflect those scenarios yet. To study an agent-based system, recent work by Costanza et al. (Costanza et al., 2014) included the scenario of changing energy prices in their deployment of their prototype to investigate socio-technical implications around such technologies. Work like this provides a good example of creative ways to test prototypes in a setting that approximates the prospective context of use as closely as possible.

2.3.2. Complex Domestic Spaces

Many of the current approaches to sensing and automatic actuation could already work pretty well in single-person households, even more so if the individual user mostly follows consistent routines. One example of these approaches is the Adaptive House by Mozer (Mozer, 2005). Unfortunately for research and development of smart home solutions, such a constrained environment is rarely the case in the world of average consumers. While necessary when conducting targeted research, working with an oversimplification of the real world can even lead to research insights that do not apply in the actual context of use. Research focusing on autonomous adaptation to sensed data without further context might lead to flawed solutions when its insights are used to create multi-user applications.

When several people are living in the same home they can have opposing or inconsistent patterns in their behavior (Youngblood, Cook, & Holder, 2005), or simply different user preferences that interfere with or contradict each other (Dixon et al., 2010). The sensed data would result in a "mixed message" to the home and likely lead to a home that is not in tune with *any* of the inhabitants. Instead of enabling smart behavior for one of the inhabitants, it becomes a source of frustration for all of them.

Increasing Complexity and Quantity of Solutions

Coping with the complexity of domestic spaces and the difficulty of predicting everyday life in an average household is one of the toughest ongoing challenges discussed in the literature (Tolmie, Pycock, Diggins, MacLean, & Karsenty, 2002). One household is never identical to another: it might have a different composition of people, or the individual household members might have other needs. Even if we focus on one individual only, that person's needs and preferences change over time (Hwang & Hoey, 2012). There are an ever-growing number of devices in the home and the set of those devices is different from one home to another (Urban et al., 2011). All these factors make it impossible to create simple solutions for automation technologies that can enable "smart" behavior independently of the specific context of use. Thus, designers and researchers face the challenge of developing solutions that will suit and benefit such diverse households and be flexible enough to deal with constantly changing needs. Home networking has been identified as an interesting focus for domestic technologies with social implications (Poole, Chetty, Grinter, & Edwards, 2008). While this only affects people using the network, smart home technologies even affect those that have not actively opted in to use them as they are still exposed to the effects of them.

The unique complexity and dynamic nature of each household is difficult to design for.

The larger quantity of devices that can be found in households also results in a larger variety of input modalities being available to a broader audience. Solutions like *Siri* (*Apple | iOS Siri*, 2015) on the iPhone are starting to make speech control more widespread; there are industry efforts to take advantage of such means of control for home automation purposes (*TTS SDK*, 2015), and in interest group discussions we also observed the development of DIY solutions. Entertainment systems that can be found in homes, such as Microsoft's Xbox and its motion sensing input device Kinect, have introduced gesture control to end-consumers and inspired novel concepts for smart home interactions (*frog | Room-E*, 2015). While the broader availability of alternative input modalities allows for new types of user interfaces, it also introduces

A growing number of input/output modalities offer more flexibility, yet challenge easy mental models.

more complexity for design. Related research has discussed what kind of device should be used (Koskela & Väänänen-Vainio-Mattila, 2004) and what kinds of smart home interfaces are suitable for different tasks or user characteristics (Zhang, Rau, & Salvendy, 2009). But obviously, the suitability of a specific medium or interface depends strongly on the specific application and on the characteristics of the context in which it would be used.

What level of granularity for control and configuration should end-users be given?

With an increasing number of alternatives for smart home solutions and a subsequent variety of standards and devices, there comes a need to allow for connections between them. One approach to that is the online service *IFTTT* (*IFTTT*, 2015) that allows end-users to connect different services, such as weather forecasts, or social media applications, with devices like lights or power sockets. Such a solution facilitates direct interoperability, addressing a long-standing pragmatic challenge for smart homes (W. K. Edwards & Grinter, 2001). However, such services are opening up a new challenge: users are faced with an overwhelming quantity of potential combinations of devices and services created by a growing user base. The question arises: what level of control or power over the configuration should be given to the user? How much should be abstracted to provide users with a simpler interface and less burden to customize the home's behavior? How will different types of interfaces affect inhabitants' expectations? In Chapter 5 and Chapter 6 we take the approach of using human-like personality in an agent interface to explore aspects of those questions.

People are interested in learning from others' best practices and solutions.

In our interviews and through discussion in the interest group meetings, we found that many people were very curious to see how others use technologies in their homes. They were keen to learn what technology can do for people with similar interests or households that are similar to their own. This need has recently been addressed by Microsoft Research's HomeOS (Dixon et al., 2010), which includes a store for smart home-related apps that users can contribute to. Similarly, IFTTT offers the ability to download "recipes" for automation, thus allowing people to have access to shared configurations for devices. Studies by Ur et al. (Ur et al., 2013; 2015) analyzed smart home-related recipes and found that even people without programming experience were able to create such configurations easily.

Iterative Integration of Automation Technologies

Discovering applications that might be of use could motivate people to acquire and add to the technologies already installed. In our empirical work (Chapter 3.3.2 – Motivations for Getting a Smart Home), our participants expressed an interest in exploring further additions, after experiencing the benefits of one feature and having developed some sense of trust. We also found that without the means to test it in the inhabited context of use, it is difficult for users to understand tradeoffs involved with automation. The monetary investment is one immediate tradeoff, but others could include, for example, lack of control in exceptional situations that the home cannot detect. The compensating benefits are often less clear: Even if people understand the general sense of a new technology, they might not see how it could benefit them in their everyday lives (Rodden et al., 2004).

Benefits and tradeoffs of automation only become clear over time.

The suggestion of putting effort into deploying and studying research prototypes "in the wild" will help researchers to identify potential shortcomings of proposed technologies and address them. But this is not sufficient to allow prospective end users of such technologies to understand well whether or not they will be of actual use to them, what unique implications they might have for their household, or give all household members the chance to develop a sense of trust. To address these challenges, novel methods are needed to study not only domestic technologies in context, but also how to make best use of existing prior knowledge about family life and domestic routines.

Novel methods are needed to identify potential shortcomings ahead of time.

Vision: Smart Homes Will Help to Identify Opportunities for Automation

When developing technologies for future smart homes, researchers will not only have to consider interoperability with other devices or services, but also how end-users can identify and configure meaningful connections between them. Future smart homes need to incorporate services to help their inhabitants to identify whether there exist solutions created by others that will suit them, their needs and their current situations.

- People might have the necessary technologies that could support them in clever ways already at hand, but how do they discover and identify this potential for automation?
- How could a home know what kind of applications would fit to a household?
- In what ways would it need to know the people it is inhabited by or the dynamics between them in order to come up with recommendations?

For people that already have smart home technologies installed in their home, future smart homes will have to help inhabitants identify further opportunities for meaningful additions and allow them to incrementally add to their installation.

To increase the interest and trust in automated functionalities, future smart homes should allow their inhabitants to incrementally develop trust in the installed functionalities and in how they work. Such homes should provide a means of encouraging all inhabitants to be involved, in order to facilitate configurations that enable automated behavior that is smart for all of the people living in one household.

Implication: Support Finding Fitting Solutions and Safe Testing of New Functionalities

Services like *HomeOS* or *IFTTT* already allow users to browse the available applications in various ways, such as identifying what apps are available for the hardware already installed or browsing the most popular applications. Inspiration can be drawn from recommender systems of other services that provide recommendations based on collected data of earlier behavior and compared to similar behavior in other users, e.g., "people who installed X also installed Y." But researchers could support inhabitants of smart homes even further in navigating the quantity of available solutions, applications, or services, as well as identifying potentially needed hardware. For example, by automatically identifying specific characteristics of one's home, or allowing the contributors to tag the applications that they share with the high-level goals that they aim to address.

People need help to navigate the quantity of possible solutions.

The number of possible combinations of devices and interactions between them is huge, so adding a new sensor, device or robot to the home could have unforeseeable results. Therefore, we further argue that it should be possible for inhabitants to gracefully integrate a new device into the home, observing the device in a trusted environment to learn how it works and whether it fits their needs. One approach to do this could be enabling a sort of "sandboxed" environment: the device would tell the user what it would have done, if it had worked autonomously. In this sandboxed environment, users should be able to gradually increase the level of autonomy that an appliance has, and make adjustments where necessary. This might provide means to overcome users' lack of interest in learning how a technology works (Yang & Newman, 2013), and shift towards what the implications of the technology would be, which users *are* interested in. This is somewhat similar to how parents watch over their children, intervening when they do something wrong (e.g., turning on the oven), and gradually teaching them what is acceptable and what is not (Schechter, 2013).

Safe testing environment could help people learning to trust automation and configure their home more.

2.3.3. Human-Home Collaboration

Autonomous technologies often leave users feeling out of control (Barkhuus & Dey, 2003), especially when there is insufficient or inappropriate feedback (Norman, 1990). Inappropriate means of interaction with automated functionalities can result in users imposing limitations on autonomous systems. For example, people would limit applications to certain devices (Dixon et al., 2010), reduce the level of autonomy of the automation (Ball & Callaghan, 2012) or only allow a robot to use a small and predefined subset of items (Pantofaru, Takayama, Foote, & Soto, 2012). If users feel more comfortable when restricting technologies, it will never be possible to exploit the full potential of automation, and as a result, the benefits of home automation will always be limited.

User-Imposed Limitations of Automation

An interest in going "analog" and escaping from "always on" technology was found to be an important user need (Mainwaring, Chang, & Anderson, 2004). In our own empirical work, we also often found that inhabitants of smart homes wanted the ability to turn off automation technologies in the home, in order for the technology to be in line with their high-level goals, such as: getting a break from technologies and feeling disconnected, or being good parents and teaching their children about responsibilities by turning off the automatic sprinkler system to have the children perform this household chore. Another situation when users may turn off technology or decide not to use it is when they feel a lack of trust due to unexpected behavior or interruptions (Czerwinski, Horvitz, & Wilhite, 2004). However, deactivated automation will not be able to support the inhabitants at all. A sensitive balance is needed to prevent this scenario, and while the user needs to feel in control, this should not require them to constantly monitor or be incessantly notified about details of the automated behavior when there is no urgent need for the user to be involved.

Issues with automation can lead people into turning it off altogether.

Diverse Set of Strengths, Weaknesses, and Interests

Besides sometimes being deliberately restricted by users, the potential benefits of automation are also limited by the human capability for information processing. A large variety and quantity of sensors in the home can create a huge amount of diverse information. Inhabitants could potentially benefit from this information, e.g., by reviewing the data to identify opportunities for automation, or simply gaining an awareness of what is happening in one's home. However, if such data is not reduced and visualized in a meaningful and reasonable way, it will overwhelm the user, perhaps to the point where she might decide to ignore available information altogether.

If data is not suitably visualized, it overwhelms the user.

Several systems aim to achieve full automation of certain functions in a smart home, such as heating based on occupancy detection (Scott et al., 2011). From related work we know that the more "intelligent" algorithms get, the more difficult it is to understand and predict their effects (Muir, 2007). A closed system can result in the user being unable to understand or read adaptive and automatic behavior, which is not only important to be able to control such technologies, but also to develop trust and feeling comfortable to rely on them (Glass, McGuinness, & Wolverton, 2008).

Fully automated functions make it difficult to establish a mental model.

Similarly, users can easily be overwhelmed by technologies that try to provide "intelligibility": insight into the workings of complex context-aware systems (e.g., by automatically generated explanations (Lim, Dey, & Avrahami, 2009), (Vermeulen, Vanderhulst, Luyten, & Coninx, 2010) or visualizations (Vermeulen, Slenders, Luyten, & Coninx, 2009), (Ju, Lee, & Klemmer, 2007). Users with a non-technical background will have difficulty in understanding the rationale behind complex reasoning (Lim & Dey, 2011a). Furthermore, inhabitants of smart homes are not even necessarily interested or motivated to understand how the technology in their home works, and do not want to invest time in learning about it (Cakmak & Takayama, 2013). Their interest may rather be driven by their immediate needs, similar to the common attitude of not reading manuals for household appliances.

Providing "intelligibility" can overwhelm the user.

While computers can outperform humans in certain tasks, in terms of speed and data processing, and can even take over some tasks entirely, there are other tasks they cannot solve, although trivial for humans (S. Russell & Norvig, 1995). In our own studies, which we will describe in the next chapter, we found that people did not consider their homes to be "smart" if they themselves are better or more efficient at carrying out the tasks the home is supposed to automate. In combination with user-imposed limitations of technologies this might lead to the unfortunate situation in which the automation technologies cannot do what they are good at and the user will never consider them to be smart. What can designers of smart home technologies do in order to create user experiences and interfaces that prevent automation technologies from being perceived as "dumb"?

User-imposed limitations can reduce potential for the home to be "smart."

Firstly, for both the smart home and its inhabitants, it will be important to understand the capabilities of what the other party can do (Bly, Schilit, McDonald, Rosario, & Saint-Hilaire, 2006) to create a system that meets inhabitants' expectations while inferring their intent if possible, and otherwise resorting to users to help resolve ambiguities. Results of work we reviewed indicated that a focus on the mediation between the inhabitants' and technology's understanding of a home is important (Cakmak & Takayama, 2013). Instead of controlling and accessing individual devices and creating connections between them using the vocabulary and metaphors that were traditionally developed for people

Understanding the capabilities of both, home and inhabitant, is important.

with a technical background, a more promising approach seems to be to "translate" and convey to the machine how inhabitants define their homes in their natural, less technical understanding.

Secondly, the fact that humans are better at certain tasks does not imply that they are interested in performing them. Consequently, there is a particularly interesting opportunity for systems that mediate between human and computing capabilities (Horvitz, 1999). As an example, while participants of studies were able to offer precise descriptions of the relationships between their use of technologies and their routines (O'Brien & Rodden, 1997), they felt that implementing those behaviors took too much effort (Bartram et al., 2011), either because of a lack of options to "program their home" (Humble et al., 2003) or simply because "they did not want to spend time learning how to program the device" (Chetty, Tran, & Grinter, 2008). If these tasks can be facilitated or accelerated by taking advantage of computing, this could lead to a situation in which automation technologies would be perceived as "smarter."

Taking advantage of each other's capabilities can simplify cumbersome tasks.

Vision: Smart Homes Will Collaborate with their Inhabitants Instead of only Being Controlled by them

We believe that the research community needs to work towards a vision of true collaboration between human and home to address these challenges of automation. Considering a collaboration with the home, instead of mere control or complete automation of the home, might help to prevent the rationalization of domestic lives which was one of the fears of inhabitants living in smart homes. Such a mediation is especially important when conflicts of interest occur between what the users want to do and what the rational machine is programmed to do (Bellotti & Edwards, 2001).

As can be seen in previous work, the existing paradigm regarding barriers to automation involves the human's responsibility for these decisions, and the technology's subsequent response.

- But what would it mean for a home to have the capability to provide suggestions or simulations regarding different configurations, thus taking a collaborative role in the decision making?

- How would this support or interrupt inhabitants' existing routines and household dynamics?
- What degree of agency and proactive behavior would be accepted?

The home, unlike the human, could conceivably have a comprehensive knowledge of its own technologies and associated challenges. The human, however, has an understanding of his or her needs and routines, as well as an intuition about the potential social consequences of technology failures.

This argument is the main driver of this dissertation, investigating opportunities for enabling this vision in future smart home interactions and exploring the varieties in designing such qualities in the following chapters.

Implication: Useful Intelligibility and Deviations from Routines

As mentioned before, context-aware systems cannot always perfectly understand the situation due to certain aspects of context that cannot reliably be sensed or inferred (Bellotti & Edwards, 2001), (W. K. Edwards & Grinter, 2001), (Suchman, 2007). This implies that they will have to rely on further explicit user input in case of ambiguities. Bellotti and Edwards propose that systems be made "intelligible" to help inhabitants build up a model of how their smart home works, including the possibilities it affords, how different technologies interact with each other, and when and why automatic actions are performed. However, there are two important problems that stand in the way of attaining intelligibility: (1) the difficulty of understanding the complex reasoning of sensing technologies by users without a technical background, and (2) users' lack of interest, and reluctance to invest time, in learning how the underlying technology works (Yang & Newman, 2013).

Design for feedback needs to consider users' skills and interests.

Another approach to keep the user in the loop is to explain such behavior using "why" or "why not" questions: Lim & Dey (Lim et al., 2009) and Vermeulen et al. (Vermeulen et al., 2010) explored how to effectively present and provide explanations of complex and autonomous applications. While much of that work is looking at pervasive environments in general, many of their findings can be applied directly to the interactions in the domestic context and will as such be taken into account for developing our prototypes. Mostly, such work has looked at how to provide retrospective feedback on automatic actions in such spaces. However, future systems will also need to provide information about potentially invisible interaction options and their potential effects, thus providing "feedforward" (Vermeulen, Luyten, van den Hoven, & Coninx, 2013).

Feedback should explain how inhabitants and their tasks are affected.

Often, related work in this field provides detailed descriptions of these problems, but until now there has not been a lot of work that suggests specific or actionable solutions to address this tension in the context of home automation. Traditionally, smart home research has approached the topic of intelligibility by taking a rather technology-centric approach, i.e., "What is your technology doing and why?" We argue that a more promising way to achieve intelligibility is to take a more inhabitant-centered approach, i.e., "How are your tasks, activities, and well-being affected by your technology and why?" These are the questions that we will be investigating further by studying smart home technologies and their users "in the wild" (Chapter 3) and, in our evaluations, the use of a familiar metaphor in current smart home deployments (Section 4.7).

Feedback needs to be tailored to the situation at hand.

One example of a similar approach for intelligibility that we consider to be very promising is providing intelligibility information that is specific to and embedded in the current task users are trying to accomplish. Yang & Newman call this *incidental intelligibility* (Yang & Newman, 2013), information that is tailored to helping users with the situation at hand. Moreover, instead of providing details about the inner workings of the system, we argue that intelligibility should be limited to the *high-level rationale* behind a certain automation action, with the potential to get more details if needed. This approach of in-situ, high-level intelligibility has already been applied successfully in recommender systems (e.g., Gmail's Priority Inbox that explains to users that a certain message has been marked as important because "of the words in the message").

Another promising approach to reduce the risk of overwhelming users with information relates to the importance of household routines in relation to technologies in domestic spaces (Leppënen & Jokinen, 2003). Routines have been extensively looked at in this context, e.g., to identify further use cases for smart home technologies (M. K. Lee et al., 2008). Digital technology will become part of even more aspects of everyday lives, and therefore cannot be separated from the domestic routines in which it is couched. Thus, it also cannot be looked at in isolation, as it becomes more interlinked and can create more side effects (Woods, 1996) that are difficult to predict by users.

Provided information should relate to a household's routines.

Davidoff et al. (Davidoff et al., 2006), Yang & Newman (Yang & Newman, 2013) as well as our own studies (Chapter 3 "Studying Smart Homes in the Wild") suggest that in order to reduce the informational complexity and meet the requirements of inhabitants, interfaces with automation technologies should rather focus on deviations from routines. Our studies confirmed this finding as our participants expressed that while their regular routines simply become an unnoticed part of their lives that they do not even need to be aware of, they wished to have better support in case of deviations from them. Previous work that provides design implications for how to deal with exceptions from rules raises the point that automation technologies should provide suggestions rather than full automation and provide "support for disambiguation" (Dey & Sohn, 2003) depending on how much inference is needed (W. K. Edwards & Grinter, 2001). People prefer to have options to choose from among automatically generated suggestions (Woodruff et al., 2007b), and leaving inhabitants in control to some extent allows for a better understanding of details of the context, especially in the case of exceptions (Intille, 2002).

Detecting deviations from routines and exceptions to allow users disambiguation can support the creation of a mental model.

2.4. Summary

In this chapter we provided arguments and a discussion for our vision of future smart homes. We envision such homes to be context-aware domestic spaces that leverage automation to proactively support inhabitants with the burdens of domestic routines, while at the same time keeping people from being disengaged and allowing them to maintain important values (e.g., have children contribute to household chores). These homes will be open to iterative and incremental integration of new technologies and appliances, allowing every inhabitant to feel in control in a home that is a safe and predictable environment.

We provided a synthesis of current challenges and promising new directions for smart homes, focusing specifically on the user experience aspects of smart homes. Our synthesis is based on an extensive literature review, an analysis of solutions in currently deployed smart homes and on our own empirical work. We discussed the conflicting aspects and tensions that exist within each of the different highlighted themes and presented our visions of what future smart homes might look like. Those visions are intended to offer ways to rethink existing work in this field and to open up the discussion for changes to the original vision of ubiquitous technologies. More specifically, we highlight that against visions of smart homes that would offer invisible and seamlessly integrated support for domestic life, living in and with an actual smart home today remains an imperfect experience.

In the remainder of this dissertation, we will address multiple aspects of the challenges that we identified in this chapter to varying extents (see Table 2-2). We will present prototypes we created to probe the design space of the visions, as well as how we followed the derived implications for research. Each theme also related to one or more of the research problems that we introduced in Section 1.2.

Table 2-2: Overview about the identified challenges, visions, implications, and the research problems/questions they relate to

Current Challenges	**Visions**	**Implications**	**Related Research Problems/Questions**
Meaningful technologies	Future smart homes will support inhabitants' *goals and values.*	Learn in and from "the wild" ➔ **Chapter 3**	Problem 1: Evolution ➔ **Chapter 3**
Increasing complexity due to more users, more devices, more modalities	Future smart homes will help to identify *opportunities for automation.*	Support finding fitting solutions and safe testing of new functionalities	Problem 2: Multi-user Interaction ➔ **Chapter 3, 4** Problem 3: Intelligibility ➔ **Chapter 4**
Understanding machine learning and interacting with artificial intelligence ➔ **Chapter 6**	Future smart homes will *collaborate* with their inhabitants. ➔ **Chapter 5**	Useful intelligibility and deviations from routines ➔ **Chapter 4**	Problem 3: Intelligibility ➔ **Chapter 4,5,6** Problem 4: Agency ➔ **Chapter 4,5,6**

Chapter 3. Studying Smart Homes in the Wild[2]

In order to learn more about the context of research problems 1 and 2, the evolution of smart homes and multi-user interactions in homes, as well as current challenges of existing smart homes, we conducted a qualitative study "in the wild." This approach addresses the identified implications of studying technologies in context to inform the challenging creation of meaningful technologies and is motivated by seeking answers to the following questions:

1. What is people's general understanding of the term "smart" in the context of homes?
2. What are inhabitants' reasons and motivations to equip their home with substantial technology requiring investment and extensive planning?
3. How are smart home and automation technologies being integrated into actually inhabited homes?
4. How do inhabitants interact with their homes and how does this affect them?

To learn about the whole process of adoption and from various perceptions, we conducted two studies. The first set of studies involved three interview sets with key groups of stakeholders in the current landscape of commercial smart home technology:

- Inhabitants of homes equipped with automation technology
- People in the process of planning or building automated homes
- Providers of existing commercial solutions for home automation

[2] Based on: **Mennicken, S.**, & Huang, E. M. (2012). Hacking the natural habitat: an in-the-wild study of smart homes, their development, and the people who live in them. In *Proceedings of the Conference on Pervasive Computing (Pervasive '12).*

In this first study, we identified the particularly interesting user group of Passive Users: people that are limited in their benefits due to their technical background and interest in smart home technologies. Thus, we conducted a follow-up study to learn more about their specific challenges and interests.

In this chapter we first describe the results of our first study, including the various motivations of our participants to bring smart technology into their homes, the different phases that are involved in making a home smart, varied roles of the smart home inhabitants that emerged during these phases, and several of the challenges and benefits that arise while living in a smart home. We then describe what we learned in our follow-up study on the specific challenges of Passive Users. Finally, we provide a more holistic understanding of the development of smart homes synthesized from the perspectives of multiple types of stakeholders through naturalistic experiences, and the identification of open areas for new smart home research to support a broader process and variety of roles than have typically been considered.

Due to our goal of creating a broad understanding of the various challenges that emerge around current smart homes and what they imply for future smart home experiences, we will present several open questions and directions for research, that are out of the scope for this thesis. In the end of this chapter, we will therefore summarize our findings and clarify which ones we are addressing in the remainder of this work.

3.1. Background and Related Studies

In-situ evaluation is important to understand the rich context of smart home. technologies.

Certain features of new technology, like reliability, functionality, or even direct effects on users, like usability (Koskela & Väänänen-Vainio-Mattila, 2004) or interface efficiency (Zhang et al., 2009), can be tested well and conveniently in a lab setting. But such a formal evaluation can be unsuitable to novel interaction concepts or untraditional interfaces (Greenberg, 2008). While features such as technical reliability might be a basic requirement for working technology they are not the only determining factors for applicability or success if they are designed for use in the domestic context (Rogers et al., 2011). Research has identified early on that it is important to consider more influencing factors for such technologies such as a home's inhabitants and their routines (Crabtree & Rodden, 2004). Understanding inhabitants' daily routines and their everyday practices is crucial for designing technology that truly addresses their needs and suitability can only be achieved within a user-centered design process if it is then tested in its actual everyday use and if lessons learned are fed back into the process.

Although automated home technology has yet to be widely adopted, it is beginning to penetrate beyond an audience of extremely wealthy or extremely technically-savvy homeowners. Posts about smart heating technologies on lifestyle blogs (*apartmenttherapy Blog | Nest*, 2011*)*, mobile phone applications that allow remote control of various home functions (*engadget | Motorola and Verizon,* 2011), and energy company advertisements about smart meters (*Yello Strom | Sparzähler*, 2015) and smart grids (*Swissgrid*, 2015) are evidence of an increasingly general audience for such technologies. The increased interest in and the use of "smart" home automation present a unique opportunity to look at how early adopters of these technologies are integrating them into their homes and lives. An understanding of how home automation is adopted and its impact on people will be valuable in providing insight about how future smart home technology should be designed to fit their needs and expectations. The growing population of people who have opted to equip their homes with smart home technology provides us with the opportunity to learn about motivations for creating a smart home, the "real-world" process of developing a smart home, and the effects of smart homes on the everyday lives of their inhabitants in a naturalistic, non-experimental, non-laboratory context.

The target user population is widening.

Research on smart homes has been carried out at various levels of abstraction: Taylor et al. explored the understanding of the general notion of "smart" in this context (Taylor et al., 2007), emphasizing the importance of the actual interaction as an aspect of intelligence. Randall provides a differentiation of several kinds of smart homes which are able to provide smart functionality beyond the accumulation of smart appliances (Randall, 2003). In this chapter we add to the understanding of what the notion of "smart" actually means to people living in smart homes.

"Smart" can mean many different things.

When we conducted our study there was little existing work looking at smart homes "in the wild" or understanding them in context to derive design implications for inhabitants' actual hands-on experiences. However, we were able to build up on methods used by the few that were done. Woodruff et al. (Woodruff et al., 2007b) conducted a home-tour-based study to study how the user group of Orthodox Jewish families uses home automation to follow the religious rules of Sabbath. Lynggard et al. (Lynggaard et al., 2012) report on a study of smart homes but focusing on the exclusive group of very rich people in high-end homes. Brush et al. (Bernheim Brush, Lee, Mahajan, Agarwal, Saroiu, et al., 2011b) conducted a study on homes with automation for a more general user group of smart home users, providing insights about barriers and opportunities of such technologies and directions as to what problems need to be solved in order to render home automation more beneficial.

Only little research work exists on smart homes "in the wild."

Only recently, some commercial home automation systems, like Loxone (*Loxone*, 2015), or special purpose devices in this building technologies context, such as Nest (*Google | Nest*, 2015), have been designed to facilitate the actual configuration and interaction for end users and specifically design for user experiences. Nonetheless, such technology is often not designed for the overall context in which it is supposed to be situated and does not take into account that the end user is rarely an individual but rather a whole group of household members. Thus, the context that has to be looked at is not only the interaction between each household member and the home, but also between the household members themselves, as well as their routines and activities within the environment that acts and reacts through installed functionalities.

Focus on user experience is still recent in consumer products.

One key area of related work has involved the identification of user requirements to provide design guidelines for the domestic environment (Davidoff et al., 2006; Röcker et al., 2004). For example, Bell and Kaye considered the notion of focusing on the experience of, rather than efficiency with, kitchen technologies (Bell & Kaye, 2002). The seminal work by Edwards and Grinter provides an overview about technical, social, and pragmatic challenges that arise in homes equipped with ubiquitous technologies (W. K. Edwards & Grinter, 2001). While this understanding of users' needs might offer hints about the motivations for advanced technology in the home, it does not directly address the

Motivations for interest in "smart" devices are diverse.

concrete reasons for integrating it into one's home in the first place. A more high-level understanding of people's general intentions regarding ambient intelligence appliances was provided by Allouch and Van Dijk (Ben Allouch, van Dijk, & Peters, 2009). They quantitatively investigated prospective users' intentions to get such appliances, based on an acceptance model for anticipated adoption and outcome expectancies and the respondents in their study only showed a low degree of intention to adopt those appliances.

As the home is more than just a building people live in, other research has focused on deepening the understanding the meaning of space within the home. Elliot et al. highlighted the importance of the diversity of locations in the home (Elliot et al., 2005), and Aipperspach et al. argue that losing heterogeneity of space, technology, and time in the home results in a less fulfilling experience (Aipperspach, Hooker, & Woodruff, 2008). This can vary between users, thus research has looked specifically at roles within the home in relation to technology. There has been other work in more specific fields on domestic routines and evolving roles of users, such as for example in health applications and Ambient Assisted Living (Ballegaard, Bunde-Pedersen, & Badram, 2006; Wilkowska & Ziefle, 2010), stressing the importance of user-centered and careful integration of (medical) technology in the domestic environment. Configuration of home networks (Chetty et al., 2007) is another example of such application-focused research. In this context it has also been identified that householders engage in different roles based on their degree of active involvement (Poole et al., 2008). Our work complements some of these findings by considering similar emerging patterns in relation to smart home technology.

Home is a context that contains a variety of personal values.

3.2. Learning about Multiple Stakeholders

To extend and broaden the existing understanding of what is involved in the creation of a smart home without focusing on a specific area of application or target user, we undertook a qualitative study involving three groups of participants to learn about the process of creating "smart homes," beginning in the spring of 2011.

3.2.1. Method

Our data was collected in two phases, the first of which focused on smart home professionals, and the second of which focused on inhabitants of smart homes and people in the process of building smart homes. Our study comprised semi-structured interviews with a total of 22 participants:

- 10 inhabitants in 7 households living in smart homes
  In 6 households we were able to conduct a home tour

  One household was interviewed via phone
- 5 people in 3 households who were in the process of planning or building smart homes
- 7 professionals

All but one of the inhabitant/planned inhabitant interviews were done in person, and all but two took place in the participants' homes. Interviews with smart-home professionals took place over the phone or on Skype (audio only). All interviews were conducted in German (the native language of the participant) except for one that was conducted in English (the common language of the participant and interviewer). The interview protocols can be found in the appendices (A.2 interview protocol for professionals, A.4 for planners, A.5 for inhabitants). All interviews were audio-recorded, and photographs and short video clips were taken during home tours when suitable.

To analyze the data, we used a grounded theory-based affinity analysis (Beyer & Holtzblatt, 1999). We first transcribed approximately 1200 data items from the interview recordings (see Figure 3-1 and Figure 3-2), and translated them into English to facilitate collaborative data analysis within our international research group. The affinity diagramming process yielded a broad set of findings; in this chapter we focus on those most related to the process of developing a smart home.

Figure 3-1: Affinity diagram of 1200 transcribed participant quotes

Figure 3-2: Examples of affinity groups

3.2.2. Participants and Households

Learning from Smart Home Professionals.

Our motivation for studying smart home professionals was to learn how the commercial processes for smart home technology currently work. We wanted to learn whether professionals get feedback from their clients, what kind, and how they integrate it in order to develop new products, which trends they follow, and also to get an initial idea about their clients and the difficulties they face. We recruited seven professionals (6 male and 1 female, referred to by participant numbers prefixed **P** throughout this chapter) from Germany, Switzerland, and Austria by contacting various companies via email. Four were system integrators for distributed bus system solutions, which provide functionality by connecting individually smart components (in this study the KNX (*KNX Association*, 2015) standard or proprietary Crestron (*crestron*, 2015) solutions); their job was to provide consulting for specific distributed bus system solutions and create custom solutions for clients. Two were CEOs of companies providing their own central solutions in which the functionality is handled by a central unit. One professional was employed at a large company which offers components for home automation. They did not receive any incentive beyond the opportunity to be acknowledged in this work. Interviews lasted between one and two hours and were audio recorded.

Learning from Planners and Inhabitants.

The second phase of data collection involved interviews with German and Swiss participants who were either in the process of planning smart homes (***planners***, referred to by participant numbers prefixed **PL**) or current inhabitants of smart homes (***inhabitants***, prefixed **I**) These interviews focused on the appeal of home automation, participants' understanding of smart homes, and the effects of the technology that they perceive or expect. In the interviews with planners we focused on their experiences with the planning and their expectations of the technology. For inhabitants we focused on the perceived effects of and experiences with the technology. Interviews with planners lasted between 45 and 90 minutes. Interviews in inhabitants' homes lasted between two and a half and four hours, including home tours. Those tours involved the participants showing us around their home and demonstrating how they use the various components that they felt were part of what they called their "smart home" (see Figure 3-3).

Figure 3-3: Participants of our study showing various components and interfaces of their smart homes

Participants were recruited on online forums and social network groups about home building and home automation, and on two system providers' online forums. Additionally, three participants were recruited through references from the professionals interviewed. The participants received gift vouchers of CHF 15 (planners, equivalent of $15) and CHF 25 (inhabitants, equivalent of $25). It should be noted that the study participants do not constitute a representative sample of households with smart or automated home technology. In addition to the geographic restrictions of our study, our recruiting method may also place restrictions on the generalizability of our findings. For example, the fact that we recruited smart home inhabitants primarily through online forums may skew our population towards people who rely on and participate in online communities for smart home information and support.

We attempted to recruit participants with a variety of technical expertise. Three of the households had little technical background represented; in the remaining six households the male adult participants had a background in information technology or electrical engineering while the females did not. Our participants came from a variety of occupational backgrounds with a large number coming from tech-related jobs. Occupations included a patent attorney, a banker, two software engineers, a CEO of a software company, two teachers, a tax accountant, a technician for building security, one unspecified part time job, a housewife, an art collector, and a project manager for usability. The participants' living situations are outlined in Table 3-1. Inhabitants had lived in automated homes for at least three years except for I1 and I6 who had lived in their new flats for six months. I1, I2 and I3 live in their homes together with children. All of the adult male household members were involved in the programming/configuring in their homes except for I7h, who outsourced or delegated all of the home automation tasks. In all cases, the introduction of automated home technology coincided with a major home renovation or a move into a newly built home, since installing a distributed bus system with independent components requires fundamental renovations unless the home has been built with channels for the necessary additional wiring. Most households had a bus system installed in their homes or in combination with a central solution, except for I1, who used only a central solution for his home automation. The homes visited were all owned by the participants, and consisted of two flats, three semi-detached homes, and two larger single-family homes. Because we recruited multiple participants from the same online communities in some cases, we have opted not to associate participants with their occupations as doing so may make them identifiable to other study participants who participate in the same forums. Instead, we provide context about participants' backgrounds only where necessary, when relating their perspectives or experiences.

Table 3-1: Participants of the second phase of our study.

House-hold	**Participant (gender, age)**	**Type of accommodation**	**Other household members**
I1	I1 (male, early 40s)	Flat	Girlfriend and two children (15, 17)
I2	I2w (female, late 30s)	Semi-detached home	Two children (10, 11)
	I2h (male, late 30s)		
I3	I3w (female, 35)	Semi-detached home	Two children (7, 11)
	I3h (male, 37)		
I4	I4 (male, 51)	Single family home	Girlfriend
I5	I5 (female, 57)	Single family home	Husband
I6	I6 (male, 33)	Flat	Girlfriend
I7	I7w (female, 61)	Semi-detached home	None
	I7h (male, 61)		
PL1	PL1 (male, 38)	Flat	Girlfriend
PL2	PL2w (female, early 40s)	Flat	Three children (5, 7, 9)
	PL2h (male, mid 40s)		
PL3	PL3w (female, late 30s)	Flat	None
	PL3h (male, early 40s)		

As mentioned earlier, we limited the scope of smart homes to homes that made use of either commercial or custom solutions for home automation, that are integrated into the home's infrastructure. All home automation systems included at least automated heating, light, or shades controlled by sensors or time settings. Some households had additional automated technologies (such as vacuum-cleaning robots or an independent automatic watering system) independent of the general infrastructure for home control. Every household had advanced climate control and/or feedback. Five households had remote access to some information about the home. Three households had functionalities based on presence detection. Five of the seven households had programmable "scenarios," meaning they were able to assign the execution of several tasks or functions to a dedicated switch or a button on an input panel.

3.3. Findings

We now describe what we learned about our participant's understanding of a "smart" home, their motivations for having or getting one, the various stages involved in that process as well as the roles they took on.

3.3.1. The Understandings of "Smart"

Although we approached this study with a particular scope on "smart" homes, we also wanted to understand what our participants considered to be smart, clever, or intelligent about their homes without imposing our definition on them. We asked participants to share their ideas with us, inquiring about what they consider "smart," "clever," or "intelligent" in their homes in general without focusing explicitly on technical aspects of the home. We asked professionals the same question to gain insights into potential mismatches. It should be noted that participants generally did not refer to their homes as "smart homes"; rather, they described certain aspects, features, or functionalities of their homes as smart.

Smart is what fits my routines and avoids unnecessary work.

A key theme that emerged was that participants considered "smart" to be that which fits, speeds up, or improves their routines while avoiding unnecessary work (I3h, I4, P7, PL3h). This could be something non-technological, such as an appropriate spatial layout of the home (PL3h, PL3w, I3h). I3h*: "The door outside [makes the basement accessible from the garden] so you don't have to walk through the living room with rubber boots on. Absolutely non-technical, but smart in relation to our routines."* Another aspect of "smartness" was that technology, no matter how powerful, needs to fit into everyday life, as expressed by I2w: *"At first I was considering the one that wet-cleans [note: iRobot's Scooba®] because I thought it would be more useful on tiles; but it doesn't have a docking station where it can recharge, so I would have to connect it every time, and, well, that's stupid."* In order to support routines in a "smart" fashion, participants felt that a home would need to be equipped with an extensive range of functionalities. They felt a home that was not fully equipped for automation or prepared for future additions of such equipment was restricted in terms of its functionality and potential benefit. (I3h, I6) I3h*: "It doesn't make a lot of sense in home automation to install one part conventionally and another part automated. It always depends on what you want, but a really intelligent or 'smart' home where you can represent scenarios… You really limit the whole house if you don't [fully equip it with the requirements for automation]."*

It's not smart if I can do it better.

Participants without technical backgrounds or a strong interest in technology reported they did not see a benefit to automation if they could still perform the same task faster or better manually (I1, I2w, I3w, PL3w). As I3w put it*: "You [addressing her husband] always wanted to [automate] the shades over there, but I felt: 'No, I don't need that,' because I'd argue that I can still do it faster myself."* In general, the stakeholders, including the professionals, inhabitants, and planners, all agreed that technology itself is not smart, but applications of technology could be smart. They felt that adding the functionality and mapping functions to the different components was what resulted in instances of intelligence (I3h, I4, PL3w, P4, P6), as stated by P4: *"It actually only becomes smart if you give the thing its function."*

3.3.2. Motivations for Getting a Smart Home

The second of our main motivations was to explore people's reasons and motivations for equipping a home with substantial additional technology which requires investment and architectural planning. Our interviews revealed several key factors and households often cited several of them as motivations.

Modern homes are smart homes.

One primary motivation people expressed in our study for getting smart homes was that they felt that a modern home should have a highly advanced technological infrastructure, even when their ideas about such infrastructure were vague. Although people in our study generally did not perceive home automation as having a major impact on their lives, they felt that one ought to consider the latest technology when building a new home (PL1, I5, P3, P7). This was the primary motivation for the two participants who outsourced the installation and programming of their homes, for example I5: *"And we also wanted a modern home; [therefore we wanted one] with technology."* We also discovered a similar attitude among planners, for example PL1, who stated: *"It's nothing you 100% need, but we're in 2011 and normal light switches like those from 40 years ago... it's always the same, nothing new."* This finding concurs with professionals' impressions of their clients' motivations, such as that expressed by P7: *"I never would have thought that they'd want such a solution [home automation], because they haven't even had a real internet connection until now… but it was pretty clear to them: they want a modern house."*

Experiencing benefits increases interest in upgrades.

We found motivation to equip the home was sometimes self-perpetuating among the participants. Just as the act of eating can sometimes stimulate the appetite, participants thought more about what else they might automate, once they felt comfortable and trusted the automated functions in their homes (I1, I2h, I6, PL2, P4, P7). *I1: "At the beginning the control was limited to shutter control and to two lights and then I noticed: actually there are a couple of functions that would be interesting, e.g. that scene control, so that I can express with one single button click: 'I want to watch TV here' and the whole environment adapts itself to it."* Adding technology and functionality in the home seemed to have the effect of feeding the interest in building on such technologies.

Hacking the home is a hobby.

Participants with a technical background mentioned a strong general interest in new technologies and smart-home functionalities. They likened investing time and money in these technologies to investing in any other hobby (PL2h, l1, I2h, I4, I6). As I2h put it: *"Instead of having a model railway I have this home."* Several participants not only spent money and substantial free time configuring their homes and adding new functionalities, but also engaged in related online communities, shared experiences, participated in interest group meetings, or attended technical talks on the subject. Several participants mentioned that they enjoy doing things themselves and that their smart home "hobby projects" provide them with a sense of achievement (I1, I3h, I6). I1 said: "*I enjoy doing stuff myself. I prefer that, actually. Not necessarily because of the possibility of saving money, but just to find out: can I do it or can't I?"*

Smart homes save energy.

Another reason for investing in advanced building technologies that our participants reported was to the desire to save energy (PL1, I3h, I4) I4: *"Saving energy in general is a reason why I decided to invest massively in insulation and so it's actually logical that you do it right and so, you need to think about electricity [consumption]."* Some participants explicitly mentioned the desire to save money and were concerned about whether the investment would pay off (PL2, P5, P7) PL2: *"Energy efficiency is one of our interests and you can discuss if it covers the cost of investment or if you get it back, but on the other hand you invest a lot of money in a home in general."* Although we will not focus on this specific motivation in the analysis presented in this chapter, it was mentioned by several participants and will be considered in greater depth in future analyses.

3.3.3. Iterative Development of Smart Homes

From our participants' reports of their experiences we learned about the various stages involved in developing a smart home and derived four key phases of developing a smart home (see Figure 3-4). Although we present these phases here as a linear sequence, it should also be noted that certain events, such as a software update or addition of a new technical component (e.g. new sensors) can trigger the return to a previous stage in the cycle.

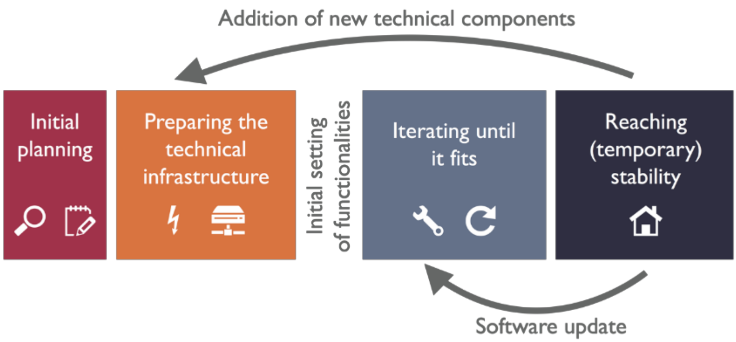

Figure 3-4: Different stages of creating a "smart home"

Initial planning

All of the inhabitants and planners (with the exception of I2) equipped their homes with automation technologies when either building a new home or performing major renovations. This agrees with previous findings (Bernheim Brush, Lee, Mahajan, Agarwal, Saroiu, et al., 2011b), and was confirmed as typical by the professionals we interviewed. In this phase Home Technology Drivers talk to the electrician, and conduct research either online or by talking to professionals. Usually with the assistance of an electrician, architect, or consultant, but in some cases acting alone, they create and iterate along complex technical installation plans.

The duration of this phase varies; professionals stated that some people begin planning the electrical installation and home automation technologies even before purchasing the property, while other participants reported starting with their planning of the automation components just a few weeks before the actual installation in their homes. In some cases, the planning phase was limited to the planning of the technical infrastructure for the home, while in other cases it extended to determining the eventual functionality and configuration of the home automation systems. Many participants spent a significant amount of time learning about specifics and the range of available technologies. In one case a participant planned out light, power supplies, and motion sensors along with the positions of the furniture in order to place components optimally and allow for extensive building automation (see Figure 3-5).

Figure 3-5: Excerpt from a participant's document to plan furniture placement, lighting, power sockets, and home automation components. E.g. the circles on the left hand side highlight the areas covered by the motion sensors.

Preparing the technical infrastructure

After the needed infrastructure was planned out, electricians or, in the case of two households, inhabitants with a professional background in electrical engineering installed the technical components such as actuators, sensors, switches, and cables for bus systems, etc. (see Figure 3-6). As explained by P7, this was not only out of reasons of difficulty but also for safety: *"The installation will always be done by electricians. For safety reasons … it will always be better off with [professionals]."* When the technical components were installed, an initial configuration of the system was done. The duration of this phase depended on the size of the building and complexity of the automation technologies.

Figure 3-6: Circuit box presented by a smart home inhabitant to illustrate the complexity of his installation

Iterating until it fits

Following the initial setup was a period of adjustment during which participants learned how the assigned functions fit with their lives and what did not work for them (I2h, I3h, I5, P5). This resulted in iterations of the system configuration. The necessity of iteration has also been reported by Brush et al. (Bernheim Brush, Lee, Mahajan, Agarwal, Saroiu, et al., 2011b). Several participants described this period as frustrating and chaotic, as reported by I3h*: "For me it's like an ongoing construction site. So it's normal that it's nonsense."* This phase often started with frequent changes to the configuration. Changes grew less frequent as the functions, assignments, and visualizations gradually became better suited to the inhabitants' routines. I1 stated, *"In the beginning, until the shutters worked properly, until the light worked, I actually modified it on a daily basis and adjusted it and tried to get it running. Now that I have the basic functionality [working], the time [between modifications] is getting longer."* The changes became less substantial, indicating a shift from major adjustments to fine tuning, as described by I2h*: "The current visualization is the third version that I created. The first and second ones differed a lot, the second and third not so much."*

Reaching (temporary) stability

After the iteration, a period of stability was reached during which the active configuration of functionality stopped (I5, I6, P5). As I6 stated: "*But [the remapping] stopped. From the beginning until I assigned the final setting [...] it was a little chaotic.*" This period of stability did not necessarily imply a state of satisfaction with the technology or optimized functionality. Particularly in households with enthusiasts who considered home automation a hobby, this state was temporary because they were still planning new functions or upgrades during these periods. In such cases, the homes soon entered a new cycle of iteration. In several cases household members were keeping track of ideas for changes by maintaining a list or notes (see Figure 3-7).

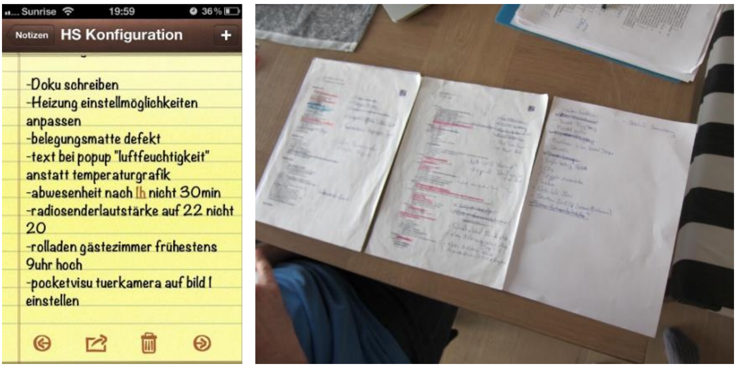

Figure 3-7: Lists of desired changes and ideas for the smart home installation ("-creating a documentation, -adjust options to set heating, -presence pad defective, -text in popup 'humidity' instead of temperature graphics, -absence after 1h not 30mins, -radio volume at 22 not 20, -shades in guest room up at 9am earliest, -set pocketvisu doorcam to picture 1") (left) kept in the note-taking app on the phone (right) kept on paper to-do-lists

3.3.4. Roles of Inhabitants and Users

One of the themes that arose repeatedly in our interviews was the variation of roles that household members assumed in relation to their smart homes; these roles appeared to apply to both inhabitants and planners, and reflected how people engaged in the planning, iteration, and use of smart home technology.

Home Technology Drivers

Home Technology Drivers have a strong interest in home automation and technical skills.

Several participants had a strong technical background, in some cases on account of having done a degree or apprenticeship in a technical field. Such participants engaged actively in the planning phase and assumed primary responsibility for the technology once it was installed. We identified this group of people as **Home Technology Drivers**. They showed a strong interest in equipping their homes with home automation technology and conducted researching on the subject in their spare time, acquiring technology for their home and trying it out (I1, I2h, I3h, I4, I6, PL1, PL2h). Three participants engaged in home automation communities by contributing to online forums or attending meetings or talks (I3h, I4, PL2h). They often reported having many ideas for further technology additions to their homes as hobby projects (I1, I3h, I6, PL2h). I1 spoke of needing to manage these ideas, stating *"I have so many whims in my head, so I have to set priorities."* In our study we identified PL1, PL2h, I1, I2h, I3h, I4 and I6 as Home Technology Drivers. They assumed technical responsibility for systems while household members turned to them for system support (I1, I2w, I3w, I4), as described by I2w: *"If something turns on or off or whatever, I simply notify him."*

Home Technology Responsibles

Home Technology Responsibles take responsibility for their smart home's maintenance.

In two of the households without members with technical backgrounds, some household members still assumed primary responsibility for the technology (I5, I7h, I7w). Although these **Home Technology Responsibles** generally did not engage directly with the technology, they were the ones who were motivated to have the technology installed, and took responsibility for having the technology repaired or adjusted by professionals as needed as reported by I5: *"I just check if all [control lamps] are green in here. If there's something red, I know, I call my technicians."*

Passive Users

Most other adult members of the households fell into the category of **Passive Users**. These participants (PL2w, PL3w, Pl3h, I2w, I3w) did not actively engage in home automation research, planning, configuration, or maintenance, but had some familiarity with the systems and controls through use. They generally left the details of planning and maintenance to the Home Technology Drivers. For example, PL1 described the decision-making dynamic with his wife regarding the technology planning: *"For those things my wife says: you can decide and then we will see."* In our study several Passive Users (I2w, I3w, PL2w) were the wives of (male) Home Technology Drivers, though our sample is not large enough to say whether these gender roles generalize to smart-home households in general.

Passive Users have little interest in home automation and a limited technical background.

Passive Users made use of the automation but were generally not interested in adding to its features or actively using it to its full extent, as indicated by I2h and I2w. Interviewer: *"Can you access your home with your phone?"* I2w: *"Not with mine."* I2h: *"Yes, you can."* I2w: *"Yes, but right now I couldn't, because it's not on there."* I2h: *"Technically you could, but you were never interested in that, in wanting that."* In many cases, however, Passive Users spend more time in the home than the Home Technology Drivers, which made them astute evaluators of the technology (I2w, I3h, I3w, I4). I3w stated, *"Technology is mainly his topic. I wait for what he shows me and then I say 'that's good' or 'that's not good.'"*

To setup technology in the home, Passive Users often did not only lack technical skills, but also motivation. Several participants just wanted the home to understand their needs and act as expected. But although they were not interested in learning about the technical details of their homes they did so simply because they had to, as reported by one female smart home inhabitant although she reported also not being interested in technology: *"Yes, I've learned all that. If you live here for 5 years, and then one thing after another fails…I was standing next to those nice people [who fixed her problems] and told them […]: I want to understand the house…my home, how it works, so that I will learn [to fix] it myself."*

Guests and Visitors

People in our study further expressed the desire to make their homes accessible to guests (I1, I2h, I4, I6) but stated that unfamiliar home technology can pose problems for visitors. Participants pointed out elderly visitors in particular as having potential difficulties with smart technologies: *"If my mother had to start with that [using a touch panel to turn on the light] … well, she can't even remember where she was an hour ago; but she grew up knowing that you have to press [a physical switch]."* As first time users of the technology, guests may be afraid of breaking something in the home, as in the case of I2h: *"In the laundry room [a guest] turned on the [loud vent used for drying clothes] instead of the light and when we got home, we said: 'Why is it running?' and then our guest said he wanted to turn on the light, but he didn't press anything, so he also didn't turn it off again. [He] simply [thought]: I won't touch anything any more at all."*

Children in Smart Homes

Participants in our study also referred to other groups of people who were affected by the technology, namely children and guests. Some participants (I1, I2, I3, P2, P7) noted how children generally become accustomed to technology easily, as illustrated by an anecdote from I3 in which they talked about how their daughter attempted to turn on the lights by waving her arms while on vacation. I1 talked about how their children were comfortable with the technology and enjoyed playing with the shades using the tablet to control them. In our work we focused more on adult Passive Users, but we consider children in smart homes also to be a very interesting topic to look at further.

Automation can affect what children learn about domestic life

Automated functionalities limit learning of cause and effect.

Besides implications of parental control there are also potential educational implications when automating home functionalities. Some of the interviewed parents expressed being a little worried about this. E.g., PI3w expressed the tradeoff between having convenient functions for herself and limiting the learning effects for her children: *"When the light turns on automatically, the kids don't learn to turn on and off the light. […] That's the negative side of the whole thing, but on the other hand for certain routine activities, e.g., when you dealing with stuff in the kitchen and have dirty fingers, those are such things [that are convenient]."* Parents were wondering if it was necessary at all that their children learn such things any more, but at the same time they perceived something of a relation between such actions as turning lights on and off, in order to understand energy consumption in general and taking over responsibilities in a household, as illustrated by a mother I2w: *"My parents were really eager to teach us to turn off the light and that the window is closed [..] that's what our kids probably won't hear at all any more in the new home, because it's not necessary any more and that raises the question: 'Does it even makes sense or is it even necessary at all in our time?'"*

Advanced controls also for parenting

With new means of controlling functionalities in the home at a distance, parents can also explicitly apply a very restrictive control to everything connected to the smart home infrastructure, as reported by I2h: *"Our daughter was an expert in not going to bed, she didn't want to go to bed. And now I can lock her light switch from my iPad and turn off her light."* Without further feedback, children might not know if the house has decided to take on an action or if something was an intended action by another person in their household. The option to either automate or remotely control functions in a home results in ambiguity.

Parents can overwrite controls of children.

Children as a security threat

But children can also be more proficient and less inhibited in dealing with technology and thus might have influences on the parents. I1 reported on how he had to change the permissions of access to his smart home control, due to his partner's children, in order to regain control of the functionalities: *"[Children of girlfriend] installed the apps on their phone and started playing. Of course they were fascinated by the technology. They were blown away. But I just had one single configuration and they had access to everything. They can still do that, but in the future they'll just have access via IP address and as soon as I change it they won't have access any more and they will need to ask me."* The same quote also expresses how the children were less afraid of breaking anything and discovered the smart home functionalities by playing around with it. The theme of children of various ages being a "threat" to predictable home automation behavior was also discussed by Schechter (Schechter, 2013); he reports on how the accessibility of technical infrastructure for toddlers, in combination with its often blinking lights, can attract them to play and break it. In his presentation of this work at the HomeSys Workshop at UbiComp (Bernheim Brush,

Children interested in playing with smart home functions can pose a security threat.

Scott, & Mennicken, 2013), he also provided the example of how children can easily "spy" on passwords without parents' knowledge. In our studies, PL1 told us how his teenage children, to whom he provided access to the smart home from their phones, would enjoy playing pranks on them by dragging the shades up and down. Due to limited customizability of access to functions he could either give them no access at all to their smart home or to all functions.

3.4. Learning More About and From Passive Users

In the study we just presented, we found that the smart home user experience was limited especially for Passive Users, because a) often they are the household members who spend the most time at home, b) current smart home interfaces address their needs and expertise the least. In our previous study this user group was underrepresented, thus we also felt that we were lacking enough insights from them to build a more complete understanding of smart homes. Thus, we decided to conduct a follow-up study and thereby to deepen our understanding of their role in the home, their unique challenges and interests in the homes by conducting a follow-up study in summer 2012.

This study was particularly motivated by some questions that emerged from our previous study:

1. How are the issues with the current interfaces related to Passive Users' lack of motivation to actively participate in the configuration of the home?
2. What is their perception of responsibility for the smart home technologies?
3. What are the dynamics between Passive Users and Home Technology Drivers?
4. Do they have specific information needs or even their own ideas on what they want from smart home interfaces?

3.4.1. Method

To elicit and collect participant experiences with their smart homes in greater detail, we took advantage of interviews (whenever possible this included tours of their homes) as well as a series of exercises and probes for our data collection, which we will explain further in this section. Participants collected their experiences over the course of two weeks using comment cards and sent them to us prior to the interviews. The provided instructions can be found in Appendix B.2. This way, we were able to prepare our interview protocols (see Appendix B.4) to probe on their actual recent experiences instead of requiring them to recall everything when the interview took place. To remind them of the (often quite large) variety of devices involved in their smart home installation, we also conducted a sketching exercise in our sessions with them.

Comment Cards

In our interviews during the previous study, we found that it was much easier to elicit reports of experiences from inhabitants of "bad" smart homes, i.e. homes in which the automation that does not work as expected or needed. They have many stories to share and they are more than willing to tell them in detail because of the frustration they still feel about situations in which they were helpless, confused or even angry at the technology. Interviewing inhabitants of "good" smart homes is quite challenging, especially when the interviewees are not interested in the technology itself. Often they are not aware of their interactions with the technology any more as it acts in the background and inhabitants do not consciously notice its influence in everyday life. This absence of awareness makes it hard for researchers to understand the specific reasons which lead to such a seamless integration. In some instances, the last interaction participants reported having with their smart home interface had taken place several weeks before we talked to our participants. To collect instances of the whole range of interactions and giving us the opportunity to probe on this variety, we asked them to fill out comment cards (see Appendix B.3) whenever they thought about or noticed the automation or its effects. These comment cards have several check boxes that are labeled with potential beginnings of sentences (e.g. "It's great…" or "I don't understand…") to facilitate expressing emotional responses and to minimize participants' effort.

Figure 3-8: PU6: "It's great…the way automatic watering system in our garden works. It starts exactly before the sunrise, saves my time and it is hidden in the grass as well. It is a miracle!" *or PU3*: "I don't understand…why the light in the basement is on (motion sensor) although no one was downstairs."

Home Sketches

It was not only difficult for our participants to remember instances of interactions, but it was also just difficult to recall the various devices or functionalities present in their homes. A sketching task that we originally introduced to get a better idea of their mental model of their "smart home" actually turned out to be well suited to act as a refresher for them so they were able to think about more functionalities of their home.

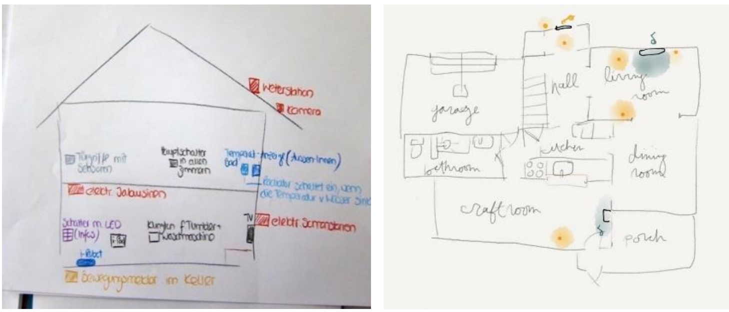

Figure 3-9: Examples of participants' sketches of their homes labeling or highlighting the various smart functionalities and devices

We provided the following task description to our participants: "Create a representation of your home that embodies how you think about your home. Illustrate what you think is 'smart' about your home." While the questions were kept very open most participants decided to sketch some kind of (floor) plan. For two participants, we had to do remote interviews. In those cases, the floor plans provided spatial context and supported the understanding of their descriptions in the interview.

The data collected with those methods was transcribed and translated to English. Two researchers independently did open coding on one of the interviews, compared the initially derived code set and agreed on a simplified subset of 18 codes that were most relevant to the objectives of the follow-up study to finish coding the remaining data. With the deepened understanding of Passive Users and smart home households we also created illustrative personas which are tangential to the themes of this dissertation, but were used to support our design process (see Appendix C).

3.4.2. Participants

Using our social networks, posting in forums of interest for recruitment advertisement, we found six inhabitants of smart homes (see Table 3-2) that considered themselves to have little to no technical knowledge. In the case of PU3 and PU4, the husbands (PU3h, PU4h) who had extensive technical knowledge joined for a more informal conversation after the official interview. Most participants lived in Switzerland and were interviewed in their homes. Two participants were living in the US and Russia and were interviewed via Skype. In one case the interview was informed by an extensive video tour showing the various functionalities recorded by the participant prior to the interview. Participants were compensated for their time with gift vouchers of CHF 40 (an equivalent of $40).

Table 3-2: Participants of the Passive User study

Participant (gender, age)	Occupation	Type of accommodation	Other household members
PU1 (female, 51)	Public service	Single family home	Husband
PU2 (female, 34)	Arts	Single family home	Husband and 4 children
PU3 (female, 38)	Interior design	Attached family home	Husband and 2 children
PU4 (female, 49)	Pharmaceutical services	Flat	Husband
PU5 (female, 36)	Stay-at-home mum	Attached family home	Husband and 2 children
PU6 (male, 26)	Company executive	Multi-family home	Wife and 3 children

3.4.3. Results and Insights

We now report on the extended understanding that we derived from the analysis of the comment cards and the interview data of our follow-up study.

Comment Cards

As to be expected, a lot of the total of 78 collected comment cards still described "negative" experiences, talking about situations which in which they felt bothered (16), concerned (1), or afraid (2) or in which they did not understand something (12) (see Figure 3-10). Many times, participants described situations in which the preconfigured rules did not match their current needs or wants, such as described by PU5: *"I'm bothered that [the] light is turned on in the living/dining area when there's still bright daylight outside!"* Other times they described situations in which there are exceptions from their regular routines, such as PU1: "*I'm bothered that the shades in the bed room go by brightness although I draw them down manually. (I'm sick and want to sleep!)"*

Preconfigured rules often did not match inhabitants' current needs or wants.

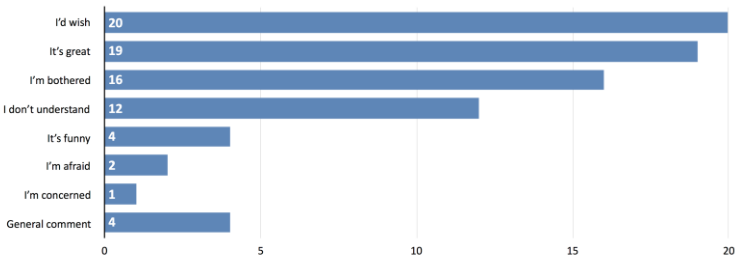

Figure 3-10: Frequency of the different categories in the comment card diary study

To a great extent the "I'd wish" responses (20) described ideas for new automation in their homes rather than complaints about existing functions. Thus, we learned about the myriad of ideas that Passive Users had on what to change in their homes. Several times, interests included new household appliance dynamics, such as PU1's wish that *"the shades at the seating area and the kitchen window would go up when turning on the coffee maker."* Or a wish to be more respondent to the inhabitants' routines,

Interest in creating automation to include appliances and routines.

such as described by PU5 who wished that *"the shades in the kid's room of [1.5 year-old daughter] go down when she's taking her noon nap."*

Achieving peace of mind is of special interest.

One goal for using comment cards was to also elicit positive experiences with the home, which participants did via their "It's great" comments. These positive experiences could help to identify aspects of home automation that participants cared about and to better accommodate their needs and priorities in future designs. Most of those comments related to the home allowing them peace of mind, which was found to be of special interest in our earlier work as well as other previous work (Bernheim Brush, Lee, Mahajan, Agarwal, Saroiu, et al., 2011b). PU2 found it great that "*the babysitter can let herself in no keys to deal with. I love this for me too, I hate getting locked out."* PU4 described how it reduced her worries about safety by considering it great that "*the command 'all off' turns off the iron automatically. Now I don't need to worry about it or have to go back."*

Means to learn and control their home's functions were limited.

While multiple comments revealed that they had no means to learn about the reasoning of why certain things were happening in their homes, only PU2 reported explicitly on being limited in terms of options to change the home's settings or being dependent on the Home Technology Driver. She described that she thought it was funny that *"[her husband] ends up being my remote when I can't find the iPad."* as only he had control via an interface on his computer and also that *"[her husband] can set up a code for a worker or someone to have access to the house remotely. Kind of wish I could."*

The intention and the findings of the comment cards were two-fold:
1) to learn more **about** Passive Users and their relationship with the home, and 2) to simply build a more complete understanding of the smart home by integrating the perspectives **from** Passive Users into our knowledge of smart home experiences. Using the comment cards, Passive Users were able to immediately capture specifics about the home's workings and limitations while performing their usual activities. For example, we learned **from** PU2 that certain control interfaces are only accessible on her husband's computer. Had we only interviewed the husband, this barrier for access might not have come up. But we also learned **about** passive. For example, how they are involved in coordinating family life and how they would want the home to better integrate and understand their routines.

Interview Results

In our previous study a lot of the input about Passive Users was actually given from another person's perspective. Thus, in this study we wanted to take the opportunity to learn about the derived assumptions directly from the actual users. In the following we are discussing our insights from the follow-up study along with the themes that emerged:

Passive Users are not "passive" per se

After our impressions from the first study, we were wondering to what extent Passive Users actually wanted to be "active," whether they really minded being "passive," and if so, whether that originates in needs that are being met or not. We found confirmation of our first work that several people did lack the interest or motivation to actively configure their home. Many times, while a general interest in actively changing things themselves was given it was just too inconvenient as they only occasionally used the interfaces and thus had to pick up how to use them every time again, such as reported by PU5: *"We stood in front of it together and programmed it, well 'programmed', we had changed it. There you can put in the date, the time. I changed that at some point, but now I don't know any more why it's going down nonetheless although I've changed it once."* PU1 explicitly described how she has to *"take the book [manual] again and take a look, how does that work and then it works"* in order to use the home's control panel. As dealing with the home automation was often a hobby to their partners, it was simply easier for the Passive Users to delegate anything related to it to them, e.g., as reported by PU2: *"Maybe also because [my husband] can [deal well with technical things], that might be why I'm more like, that I think 'Well, I simply tell him that in the evening when he comes home', maybe you try it a little less than if you'd be alone, then you simply would need to be able to do it somehow."*

Inconvenience of configuration and controls negatively affected the interest to engage with the home automation.

Preferences for interacting with the home differ

We were interested to learn more about what information we would have to include or present in a new smart home interface and whether we could inform our design by specific ideas from our target users. In our follow-up study we found that in some cases, well-intentioned ideas by the home-configuring partner had to undergo several iterations in order to fit the household's routines or dynamics. E.g., while the idea of sound notifications of the washing machine or safety-related information were also in the interest of the Passive User, in the daily usage that did not work out, as reported by PU3: "*In the beginning we had a different sound [for the laundry machine], but it got on our nerves very quickly.*" PU3h: "*I tried something out and she said: 'TURN THAT THING OFF!'*" PU3: "*It's annoying! […] you got scared every time, that someone's talking again so that I said: 'No! Rather simply a ring tone […] it sounds different than the door bell so you know: ok, it's the laundry machine.*" As mentioned before, the differences in confidence with technology also affect the extent to which Passive Users want to control their home in advanced ways, as described by PU1: *"[My husband] would want to set stuff via mobile phone, [me] not really, because I say, I don't trust this whole technology."*

Inhabitants' preferences for how to interact with the home varied.

Partner plays an important role on the smart home experience

Trust in the partner's configuration influenced trust in the home.

Despite having collected many instances in which their home did something that they did not expect, participants reported generally trusting their homes if they felt they could trust the person that carried the configuration out, e.g., as reported by PU4: *"If [my husband] programmed it, it's alright"* or by PU2: *"Because [my husband] programmed it like that and he told me how he does it or when he does something. That's why I know in normal situations how it should work."*

Passive Users feel that they are not in the loop

Limited access to suitable interfaces made Passive Users feel out of the loop.

Our previous study revealed that Passive Users felt that they are often not on top of things if it comes to the functionality of their smart homes. Thus, we wanted to investigate the reasons that they do not feel in control and learn about opportunities to improve their feelings. Sometimes this feeling was simply because of limited access to the devices that had the software to configure the home, such as in case of PU3: *"I have no idea, where I would have to got to look at it. Because that's with him in the computer, all so, pfff, well I would have absolutely no overview, how it's set, where I would have to do what."* In other cases, it causes frustration because the limited transparency of changes to the homes' configuration and the effects that it has on the home's behavior as described by PU2 after not understanding why her stove did not work one day: *"And so I told [my husband]: 'Please let me know in advance and don't do such stuff that concerns my devices."*

3.5. Challenges

Based on these two inquires involving multiple stakeholders we now identify higher level challenges. We learned that the process of getting and using smart home technology yielded interesting challenges and effects that varied in impact for the different inhabitants. Especially interesting was the fact that the process of planning, integrating, and iterating upon the technology seemed to have a more notable impact on people's lives than the use of the technology itself once installed and working.

3.5.1. Automation Doesn't Re-invent the Home; it just Makes it More Convenient

Surprisingly, despite the cost and effort of instrumenting the home with automation technology, participants pointed out very few direct benefits they derived from the technology or major impacts on their lives or practices. Instead, participants described the effects of the technology as small conveniences rather than as substantial support for routines or tasks. People perceived the installed technology as enhancing their level of comfort, but also pointed out that the technology was limited in the help it could provide. PL2w explained the distinction: *"You try to make work a little easier with modern technology. But I still have to do my laundry myself. A laundry chute is there; it carries it in one direction, but besides that..."* Other participants, including professionals, believed that technology does not enable new functions, but incrementally improves what one can already do, as stated by P2: *"It's not like you have a rocket engine in the basement or anything like that. It's comparable to what you had before – just a little smarter and cooler."*

Automation enhances comfort, but does not enable new functions.

3.5.2. The Challenge of Planning for Unfamiliar Technology

It is often difficult to predict what the impact of a new technology will be on one's life and practices; in the case of smart home technology the stakes are particularly high because of the investment involved and the fact that one is not merely purchasing a gadget, but instrumenting one's entire environment. In the planning phase, information about home automation technologies, such as that found on websites, brochures, or manuals, often offers technical details but is less informative about their potential effects on everyday life. At the start of the planning phase, participants reported not understanding potential benefits of technologies (I1, I2h, I3, PL2w) and therefore had difficulties prioritizing those technologies against other needs in the home. Participants without technical backgrounds reported having to rely upon other people's experiences and expertise, and therefore feeling powerless. I5 related a particular incident in which a switchbox installed by electricians proved to be too small, leading to frustration on her part. However, she felt that she could not have prevented the error, as she did not have technical expertise and therefore had to go along with the decisions of the electricians.

Understanding benefits of automation is difficult.

Passive Users seemed to be skeptical about the general use of home automation technology, as highlighted by PL2w's statement: *"It offers many options, but it's really very complex. The question is: do you really need this?"* They relied on other people's experiences regarding the usefulness of a solution (I2w, I2h, I7). I2: *"We learned from our neighbor's experience regarding the vacuum cleaner [iRobot's Roomba®], and he said it's an amazing device. And that's why we bought it."* Although they did not participate actively in research or planning, they offered input on other decisions that influenced home automation, especially regarding budget decisions as stated by I3w: "*He came to ask when…" I3h: "…for budget planning." [both start laughing] I3w: "Yes, exactly. But besides that – not at all."*

Professionals offered another perspective on the challenges of planning. They reported that customers have difficulties understanding the available technology and options (P1, P2, P4, P5). P2 said: *"It just doesn't make sense to people … [that] they need power line switches if they [just] want to* *have access with their smart phone. They don't see the connection.*" P7 illustrated this challenge by contrasting smart homes with more familiar technologies: *"The whole issue of home automation is still so remote. For cars, everyone knows what's possible."*

3.5.3. The Challenge of Getting High-level Expert Advice

Participants also reported frustration over being unable to access authoritative and expert advice for high-level decision-making, despite the existence of experts. Professional system integrators (i.e. home automation experts) typically only provided information on the systems that they offered, and other types of home experts, such as electricians and architects, were rarely able or willing to provide information about home automation technology (PL2w, I2w, I2h, I5, P5, P7). I2: *"That was actually the biggest challenge: from whom do I get information about what I really can do, which elements I can buy or use, that have what I want…?"* Participants felt they needed an overview of available products in order to identify their needs and choose the right product or combination of products, as stated by I1: *"There was something that I was looking for, but couldn't find… a website that is comprehensive, including all manufacturers, that is unbiased… that presents the various systems, comparing them, showing their advantages and disadvantages. That would have been genius."*

Interest in overview and comparison of available solutions.

3.5.4. The Tension Between Comfort and Control

Most participants of our study deemed the automation of some actions in their homes to be convenient and to increase their comfort, but at the same time this increased automation led to a perceived or actual loss of control that decreased the actual positive effects. They reported a tension between comfort and control, but it was perceived very differently, seemingly dependent on the degree of technical skills and amount of involvement in the actual setup of their smart home. I4 talked about the override functions he had created for the home, and PL2w said she feared becoming *"a prisoner of the system."*

In some households there were members who insisted on having means to manually override the automation just in case they might need it. Although they did perceive a gain in comfort when the home acted correctly and understood what they wanted and needed, their frustration when it ever failed to do so overshadowed this benefit. E.g., I2w expressed frustration with automated functionalities as well: *"It bothers me when it turns on the light ten times and I actually don't need it."* Most Home Technology Drivers (I1, I2h, I3h, I5, PL1) expressed indifference to some of the negative effects or constraints resulting from home automation. This resignation to a sub-optimal configuration was illustrated by I3's statement: *"If that happens once or twice a month [the light turning off unexpectedly], then it's at a relative low priority for the 'construction site' [our home]."* Or as stated by I2h: *"I just accept that the shades are down and then I just go to the door to look outside."*

Failing of automated functions overshadowed their benefits.

Participants reported that they did not understand how the automated functionalities worked because they could not understand their logic, and therefore even explicitly refused to try to understand it, as illustrated in this example: I2h: "*The vacuum cleaning robot is not efficient in terms of cleaning faster than manually […] you absolutely shouldn't observe it, or you will go crazy."* I2w: *"You get the impression: 'what logic does he follow.' He goes to one corner then to some other and then somewhere else and you think: 'Huh, why don't you just go there and then you have everything done.' But because of that: simply don't watch, he'll manage to do it."* Our participants wanted to have their home understand them and not the other way around. But in order to establish trust there has to be a mean to establish a mental model of how one's home's technologies work and interact (Bellotti & Edwards, 2001).

3.5.5. Experimenting and Testing

As mentioned above, Home Technology Drivers often considered the installation and iterating to be a hobby, as illustrated by I4's comment: *"In summer I work outside [in the garden] and in the winter it's the visualization and the device automation."* We found that adult Passive Users often acted as evaluators (I2w, I3h, I3w, I4, I5) for the drivers' "experiments." Interviewer: *"What turned out to be useless?"* I2h: *"The motion sensor in the restroom. You [addressing his wife] said: 'No, I don't want that, there needs to be a switch again.' So I added the switch again."* Passive Users tended to think about the technology in terms of how it supported their routines and tasks, as exemplified by I3w: *"So when you come home on a winter evening and you've got your hands full of stuff, you open the door but you still have stuff in your*

Passive Users often acted as evaluators to Home Technology Drivers' experiments.

hands. So I wanted [the light to turn on automatically] without having to look for the switch." Home technology drivers, in comparison, emphasized the process and implementation. As I1 put it: "*It's not really about [using the technology], but the realization… building this apartment; planning everything, then building it, then making it work. And once everything is done… it's nice to be here, but then new thoughts start: what else could you do?"* Parameterizing, adding new functions, and making it work are perceived as rewarding experiences that provide a sense of achievement, reported explicitly by several of our participants (I1, I4, I6). These findings echo those of previous research that explores the sense of achievement in DIY and repair projects (Buechley, Eisenberg, Catchen, & Crockett, 2008; Kane, Wobbrock, & Ladner, 2011).

3.5.6. Lack of Transparency due to Multiple Users

As there was usually just one person who knew about updates or changes to the configuration, other household members were therefore not aware of changes to the smart home control or behavior. This lack of transparency and feedback led to confusion, frustration and in some cases to negative attitudes towards future changes or a greater extent of automation, as illustrated by this smart home inhabitant: *"[The system integrator] activated that [scenario] for us once, but we didn't know that, so I thought: 'Damn, you left the light on again! How can that happen? Why is the light on all night long? That shouldn't be like that?'"* The difference in roles and responsibilities in smart homes also led to issues of control, such as in one example in which a technology driver (I6h) reconfigured the home in a way that made certain functions unusable to Passive Users: *"She wanted to turn on the light and then the switch was for the other light because I reassigned it, and then the shutters rolled up on one day, and on another it was a light switch again."*

Effects due to changes of one user were not transparent to others.

3.6. Avenues for Smart Home Research

Our study has uncovered many of the tensions, challenges, and benefits involved in the process of integrating smart home technology into a household. By considering the process in a holistic fashion, we have also identified three themes that go beyond what we address in this dissertation, but which we believe to be highly important and interesting open areas for smart home research that warrant further exploration.

3.6.1. Design for all Phases

Potential for supporting users in their planning and iteration phase.

Much research on smart homes has focused on providing configuration tools for smart homes, ranging from complex programming environments to simple visual programming tools. These tools are most applicable after all of the necessary technology has been installed and integrated. However, our research has revealed that people need support not only in deciding how to configure their technology, but also in deciding what technology they will need. This phase of planning for a smart home is critical, but support for it is currently fairly minimal. We believe that there are important opportunities for research to support this phase, in terms of presenting people with information about potential technologies that will inform them about their options and help them to make the best decisions to suit their needs. Additionally, we believe there is an opportunity to provide support through tools and technology that help people to get a feel for how the technology might affect their lives or activities, possibly in the form of simulations or scenarios integrated into the planning process. Similar support might also be valuable in the iteration phase, during which households are trying to optimize the configuration of their technologies. Better support for informing inhabitants of the outcome of choices and allowing them to explore options more easily might help to streamline this phase, to help people get the most out of the technology, and alleviate the frustrations that people experience with technologies that do not fit well with their lives or that do not work as expected. These directions also present opportunities not only for the design of new technology but for the design of new experiences as well. Although we will not address this opportunity for research in the remainder of this dissertation, we will refer back to its importance in the discussion of our findings in Chapter 4.

3.6.2. Supporting Hackers and the Hacking Process

One of the clear emerging findings of this study was that the "hacking" of the home was both a primary motivation for installing smart home technology and a perceived major benefit for some members of the households. Some Home Technology Drivers seemed to want to program the technology as much as they wanted to make use of it. One important direction of smart home research thus far has focused on simplifying the configuration and administration of home technology to make it as universally accessible as possible and eliminate the need for "system administrator" knowledge. We agree that this is an important direction to pursue. At the same time, our findings suggest that there may be an important direction for open research into providing support to household members who want to engage with the technological infrastructure by hacking the home. Providing appropriate tools would not only support the hobby aspect of smart homes but also facilitate experimentation and innovation, and possibly provide solutions that are better fitted to the needs of individual households. This avenue of research could also present interesting design challenges in terms of how to support the hacking process in the larger household context. This might include considering how to minimize inconvenience, avoid disruption of routines, and communicate process information to others in the household.

Tools that facilitate experimentation and innovation could help inhabitants in creating better-fitted solutions.

3.6.3. Exploring Support for Passive Users

Although the Passive Users in our participant households did not engage directly in the planning or configuration of home automation technology, we found that their needs and practices still had an influence on its design and use. The Passive Users were asked to give approval for certain decisions and provided important feedback with regards to optimizing the configuration of technologies to suit the household. Although these users wanted to give others in the household freedom to "hack," it was apparent that they still had some investment in ensuring that the technologies worked as expected and needed. We therefore feel that there is an important open avenue of research to be explored on how other members of the household can shape and influence the technologies without investing significant time or effort, and possibly while avoiding the need for direct interaction with the

Passive Users' extensive knowledge of the household could help to better shape a home's configuration.

system. For example, it may be worthwhile to consider how household members can provide feedback to systems or to technology drivers in novel and implicit ways, or perhaps ways to support a more collaborative evolution of the home technology.

3.7. Summary

By taking a broad approach to studying real-world manifestations of smart home technology, we have uncovered practices and implications that go beyond the interactions of technology enthusiasts with home technology, to include a variety of stakeholders and an extended process of planning and development. In addition to shedding light on the impacts of these technologies on homes and everyday life, we believe they point to important new areas for the research community to explore.

From the various challenges and potential research avenues that emerged, we found that some are particularly related to our research problems. Due to Passive Users' important role in the coordination of the household, we believe that providing them with suitable support for active engagement with smart homes will improve all household members' experiences with the involved technologies. Additionally, in our studies these were the users spending most time in the homes thus being affected most by sub-optimal configurations, without the abilities to fix them themselves. Thus, in the next chapter we focus on the avenue to "Explore support for Passive Users."

Part 2: Probing Different Interaction Approaches

We learned from our empirical work that interacting with smart homes and Internet of Things devices is still far from being a seamless experience as there are often many different and inaccessible interfaces involved. Among the multiple aspects of the current smart home reality as well as emerging trends in research and industry that we identified in Part 1, we found a need to learn more about how user experiences will have to be designed as the home gains more autonomy and progresses to its own entity in a household. Along the theme of helping people "collaborate" with their home, to assist them not only with the increasing complexity but eventually, create technologies that are more meaningful to a home's inhabitants, we set out to probe into the potential design space of proactive homes.

In Part 2, we describe three approaches inspired by practices or characteristics of human interactions to investigate the potential for "personifying" aspects of smart home interactions. More specifically, we have taken inspiration from how people communicate their **routines**, **personalities**, and **emotions** to interact with each other and we explore what it would imply for a home to do that in a similar fashion.

- **A home's routines:** We developed a concept and a prototype for an interface for current smart homes based on our insights on the different people sharing a household to address the issue of better supporting Passive Users. The developed interface uses a familiar metaphor, a calendar, to visualize various different functions of the home in a consistent and more accessible manner. The main goal was to address the problems of different skills in users and to evaluate the potential to make homes "smarter" by conceptually connecting the routines of the inhabitants and the home in a calendar interface.
- **A home's personality:** Looking more into the future, following the trend of agent interfaces and the potential for human-home collaboration, we wondered whether people's capabilities of interpreting personality traits in order to set

expectations for behavior and responses in others, could be used to facilitate communication and interactions with a smart home. A similar "getting to know each other" phase for smart homes, as described in Section 3.3.3 (Iterative Development of Smart Homes), is very challenging and annoying to inhabitants. Thus, we conducted user enactments in a lab prototype, helping us to learn about attitudes towards proactive behavior expressing two personality composites.

- **A home's emotions:** In human interactions, people can use other people's expression of emotions to interpret their behavior or what they say. Thus, we wanted to learn whether analogies would apply to objects in the home as well and whether an "emotional" vocabulary could be used for providing subtle cues in interactions. We conducted exploratory studies with a provocative prototype that elicited responses in study participants to learn about the potential of the concept as well as limitations for domestic technologies that aim to leverage human-like characteristics in their interactions.

Chapter 4. Routines: Integration via a Calendar

In our earlier studies we learned about several potential understandings of "smart" (Section 3.3.1). One of them was the perception that a home *"is only smart if it suits my routines."* In the light of our exploration to learn about the personification of a smart home, we interpret this as a potential for making the home "smarter" if it could better support the coordination of the homes' routines with those of the inhabitants. To explore how this could be done, we decided to develop an interface that would visualize both categories of routines within the same interface and further study whether such an interface addresses the identified challenges of intelligibility by the multiple inhabitants with different technical skills.

In this chapter, we first describe the iterative process of our concept development (see Figure 4-1) as well as the design and implementation of our prototype Casalendar, a calendar interface which integrates smart home technologies with inhabitants' calendars. Finally, we report on the studies we conducted to evaluate the concept and what we learned from our two case studies in an "in the wild" deployment.

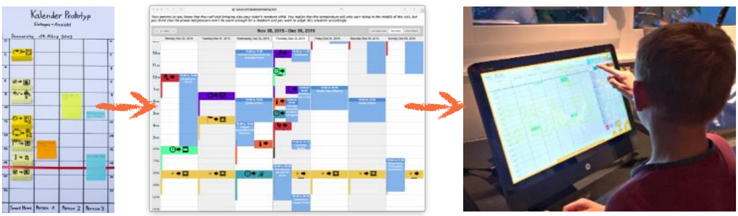

Figure 4-1: Three iterations of Casalendar

4.1. Motivation and Approach

Lack of understanding has a negative impact on the user experience.

As we described in Section 3.2, homes are often heterogeneous environments with multiple inhabitants, yet smart homes are often configured by only a single inhabitant with technical expertise. This leaves others unaware of why the home is automatically performing particular actions or how to stop it from doing so and makes Passive Users in particular feel that they are not in the loop any more, as we found in our follow-up study. Having a proper understanding is crucial for being able to control such a system and develop trust in it (Bellotti & Edwards, 2001), which ultimately affects how satisfied people can be with their most personal space – their home (Isalgue, Palme, Coch, & Serra, 2006).

Collected data has potential to improve the understanding, but the right visualization is key.

A variety of data on behavior in homes is collected due to the increasing adoption of connected sensors and actuators in domestic environments. Most of the currently available smart home interfaces allow inhabitants to view the state of individual devices or functions and access log files about past events or sensor values. However, much of this data, for example, numerical values for temperature and brightness values around the house or binary values for motion triggers, is difficult to interpret when presented as uniform number or text entries in a log file. In general, mere access to raw data is not helpful to most users. Therefore, it does not contribute to forming a useful mental model of one's automated home (Strengers, 2011). The way in which data is represented can also impede access to the technology for household members without the required background or training.

Our empirical work described in Section 3.5 revealed that the low accessibility of the tools used to configure a fully automated home will often have a negative impact on the overall user experience and leaves many of the opportunities of automation untouched, and that especially for those Passive Users, this leads to frustration about the lack of transparency and control of things happening in the home. The data the home collects could potentially reveal a lot about the behavior patterns of a home and the household, with a better presentation. This would help to facilitate the understanding of what is going on in one's home and provide a more easily accessible interface, and thereby democratize access to the technology and data within smart homes, which is one of the overarching goals of this thesis.

Once a smart home is set up and programmed, its installation is rather inflexible (Stringer et al., 2006). As identified in Section 2.3.3 (Human-Home Collaboration) the home acting and reacting according to its own preconfigured rules and agenda will increase even further in the future. To make this behavior intelligible and to get the most of such an automatically acting entity, it needs to provide a means to access its behavior as well as to be incorporated into the routines and dynamics of the household it should support. Therefore, proper communication, coordination, and collaboration, which would then include the home itself, are needed between the members of a household. A tool that has already been proven successful for typical households to manage routines and to communicate and coordinate with others is the calendar; often, this is a family calendar that all members have access to, e.g. many households use a paper calendar in the kitchen or another common area (Neustaedter, Bernheim Brush, & Greenberg, 2009).

A configured home has its own routines that needs to be taken into account.

Unfortunately, the home's behavior does not always adjust properly to its users. This is mainly due to the preconfigured rules for automation which are static and thus cannot easily accommodate the frequent exceptions from the household's regular routines (Bernheim Brush, Lee, Mahajan, Agarwal, Saroiu, et al., 2011b). As the calendar is a widely used tool for providing a temporal overview of multiple events and allows users to spot potentially conflicting entries and deal with them (Neustaedter et al., 2009), we consider this a promising approach to explore it in the context of smart homes. While one goal of automation could be to not require the inhabitant to know anything about the inner workings, instead we believe in the approach of helping the inhabitant to learn how to actively take control when it is needed (Larson & Intille, 2003). This goal would be in line with our vision that future smart homes will collaborate with their inhabitants as introduced in Section 2.3.3. To facilitate a dialogue between smart homes and their inhabitants, we turn to the familiar calendar metaphor. Shared calendars are widely used by families, have been integrated into their routines, have proven to be useful for coordinating a family's everyday life, and facilitate intra-family communication (Neustaedter et al., 2009).

Families' interactions with calendars can be customized to their specific needs, leading to numerous variations of the calendar concept. As more families turn to digital calendars, researchers have explored adding additional information to calendars, for example, location information to support family coordination (Davidoff, 2010) or directly embedded physical activity data to ease access to that information (Costanza et al., 2014).

In the remainder of this chapter, we report how we investigated the suitability and value of calendars as a familiar interface metaphor which allows communication in two directions: 1) from home to inhabitants to facilitate their understanding of the home's routines by visualizing its actions, 2) from inhabitants to home to provide the home with more of its inhabitants' context through their calendar entries. This chapter is structured as follows:

1. We describe related work on studying calendar usage, visualization of smart home behavior and smart home interfaces, and using calendars to visualize data. We also compare the advantages and disadvantages of existing smart home interfaces that are commonly in use, to provide background for our argument for why we consider the calendar metaphor to have strong potential.
2. Then we report on the three iterations in our prototype design process, including two prototypes tested in the lab as well as our field-researched case study of our final prototype.
3. Finally, we report on our findings from this field trial including emerged usage patterns, the appropriateness of the calendar metaphor and how it supported the democratization of access within smart homes, resulting in several design implications.

4.2. Related Work

4.2.1. Visualization of Data, Control and Intelligibility in Smart Environments

In research, related work on visualizations of logged sensor data in the home often has a specific application focus, such as increasing awareness of energy consumption (Neustaedter, Bartram, & Mah, 2013), network usage (Chetty et al., 2010) or water consumption (Froehlich et al., 2012). Related work for smart home interfaces often focuses on improving end-user programming of context-aware environments (Dey, Hamid, Beckmann, Li, & Hsu, 2004; Truong, Huang, & Abowd, 2004) or exploring different means of input such as gesture control (Kühnel et al., 2011), eye interaction (Bonino, Castellina, Corno, & De Russis, 2011), or exploring opportunities for speech interaction (Bernheim Brush, Johns, Inkpen, & Meyers, 2011a). Commercial interfaces usually simply offer users an interface (e.g. on a tablet PC, mobile phone, or in a web browser (Koskela & Väänänen-Vainio-Mattila, 2004)) in which they can access the controls for the various devices and functionalities in the home, however, without supporting a specific higher-level goal, such as preparing the house for a dinner party or for a longer vacation. Our Casalendar interface is similar in this respect and does not afford a specific use case or promote a specific functionality. However, the primary aim of our interface is to elicit data on the users' interests and the way they intend to apply the knowledge they may gain.

To enable user control and comprehension of building technologies, researchers have developed a variety of tools for end-user programming and the visualization of components and functionalities. Some work takes advantage of familiar metaphors: (Humble et al., 2003) developed a tablet PC application that allows inhabitants to connect and configure a range of ubiquitous devices for domestic environments by combining jigsaw pieces as well as by assembling actual physical jigsaw pieces (Rode, Toye, & Blackwell, 2004); Truong et al. (Truong et al., 2004) uses a virtual magnetic poetry metaphor to translate the user's description of an intended behavior into instructions for the related devices.

More general research on the area of end-user programming explored what kind of devices in the domestic context are programmed, by whom and how (Rode, Toye, & Blackwell, 2005). They also identified gender differences in approaching programming of technology in homes (Rode et al., 2004). Those differences in terms of programming approaches, as well as different motivations in configuring a home at all, stress the importance of our goal to also facilitate the actual interaction when trying to use the smart home interface to perform a control or information retrieval action.

4.2.2. Visualization of Data in Calendars and Other Temporal Metaphors

The calendar has been used as a canvas for visualizations in many areas of application. Costanza et al. (Costanza et al., 2014) made use of calendars to allow people to better understand varying costs of energy in the context of smart grid applications, while Laschke et al. (Laschke, Hassenzahl, Diefenbach, & Tippkämper, 2011) provided an in-situ visualization in the shower using the calendar metaphor to increase awareness for water consumption. Informative data was also integrated in Huang et al.'s (D. Huang, Tory, & Bartram, 2014) work which visualized step counts from activity trackers next to people's calendar entries in order to increase awareness of such data and lower the threshold for engagement with it. Our prototype aims to incorporate the multiplicity of different devices which a home comprises and offer an overview of the various functions it provides. The goal of this work is to learn whether the calendar metaphor works differently for smart home data and how suitable this metaphor is for allowing people to improve their understanding of the overall behavior of their home and the events that are taking place within it.

4.2.3. Calendar Usage

Besides providing a strong metaphor for time-related data, calendars are also a well-established tool for coordination, communication, and collaboration between people (Palen, 1999). In the context of families, this has been looked at in depth by Neustaedter et al. (Neustaedter et al., 2009), whose understanding of calendar types and their content informed our prototype designs. Substantial related work has looked at organization, coordination, and communication in domestic environments. E.g., they identified time-based scheduling, especially through family calendars, as one of the key ways in which people organize and communicate events in the home. In this work, we primarily focus on public awareness calendars. As shared digital calendars are commonly used for multiple purposes, they can contain content of various other types of calendars, such as personal mobile calendars and task and chores calendars. Calendars have turned out to be helpful for families to manage their routines and manage conflicts (Davidoff, 2012). Motivated by this, we are exploring whether similar benefits can be transferred over to the interactions between the home and its inhabitants.

Tullio et al. (Tullio & Mynatt, 2007) created a shared calendar augmented with additional information and explored its use in the work context. This calendar interface contained predicted information for the users, aiming to facilitate interpersonal communication. In our interface and study, we explore the usefulness of the calendar metaphor mostly by looking at the participants' interaction with past smart home data, but we included potential predictions of smart home behavior in order to perform a preliminary probe on potential uses of such information. However, the contribution of our studies and the derived insights aim to add to the understanding of how to facilitate interactions with a smart home and are less about advancing the research on calendar interaction itself.

4.3. Comparing Smart Home Interfaces

In chapter Section 3.5.4 (The Tension Between Comfort and Control) we discuss that in order to increase acceptance and trust of automation technologies we need to foster intelligibility (Muir, 2007). This understanding of how a system works is necessary for various types of control in such a home: e.g. after the physical installation of the hardware, the inhabitants (or the technicians they hire) configure "pattern control," the rules that connect sensors and actuators, to automate certain behaviors (Koskela & Väänänen-Vainio-Mattila, 2004). Then they also need to set up interfaces for "instant control" (Koskela & Väänänen-Vainio-Mattila, 2004) that show the current state and allows control of the home's functions. Additionally, smart home technologies are often not entirely automated, but rather are mixed-initiative systems (Horvitz, 1999) in which the technology provides the means to run automated actions based on explicit user input such as creating a scene that the inhabitant can trigger to execute an entire set of actions and/or put the home in a state in which it reacts in a certain way (e.g. an "away from home" scene could enable different notifications to be sent to the user and to be monitored). To enable better smart home experiences, we need to facilitate informed control when necessary and to enable an appropriate level of understanding. Due to the varied technical backgrounds that inhabitants of such homes have, we also have to take into account that they are not necessarily interested in actively controlling or configuring it. Thus, we need to provide a familiar interface that inhabitants already use as part of their daily routines.

By combining our understanding of the context, the users, and the involved tasks, we derived that an improved smart home user interface should:

- Help build an understanding of the home's actions (to address previously identified challenges and implications, such as "The tension between comfort and control" in Section 3.5.4, "Lack of transparency due to multiple users" in Section 3.5.6, "Useful Intelligibility and Deviations from Routines" in Section 2.3.3)
- Support inhabitants in adjusting the home's behavior to their routines (to improve the perception of a home being smart as introduced in Section 3.3.1)
- Be usable by all family members (to accommodate the various roles of the smart home inhabitants introduced in Section 3.3.4)

Instead of focusing on these user requirements, common commercial smart home interfaces are rather designed with a focus on a few specific use cases, such as (1) **viewing the current state** or (2) **configuring settings** of a specific device knowing its specific location, or getting a (3) **spatial overview** of the current state of a subset of functions. This does not imply that they cannot fulfil the requirements; however, current interfaces lack a proper support of them.

4.3.1. Categorical Menu

Interfaces for the first use case are commonly organized in categorical, often hierarchical, menus based on the device category or location (see Figure 4-2). They usually contain specific control elements for each type of device, which allow users to see the current state of the device and change its configuration. The main advantage of categorical menus is that they allow the user to quickly access the device settings when they already know what they are looking for. Moreover, the configuration interface of each device type can take up the whole screen space and display more detailed state information and options for control. Providing a holistic overview of the entire home is not the primary concern of such interfaces.

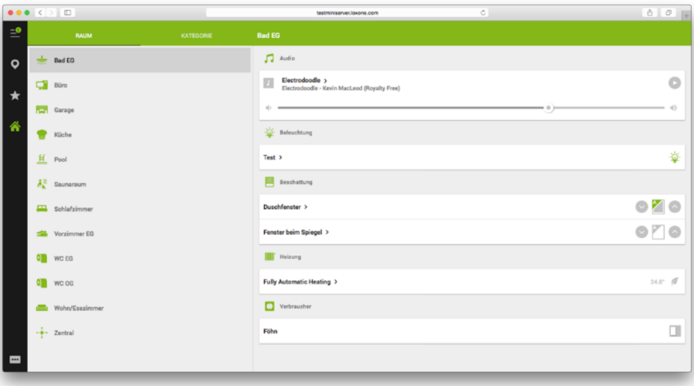

Figure 4-2: Screenshot of Loxone's web user interface using a list with room (Permission granted by Martin Öller, Loxone)

4.3.2. Spatial Map

Interfaces that are based on spatial maps provide a hierarchy-less overview of the entire home or selected floors (see Figure 4-3), allowing novice users to locate the control element for a specific device based on their knowledge of the home's spatial layout, and thus provide **direct access** to a specific set of functions or devices. Such floorplan-like interfaces provide **glanceability**, allowing users to spot any irregularities of device states at a glance, for example by indicating any open windows with a red circle.

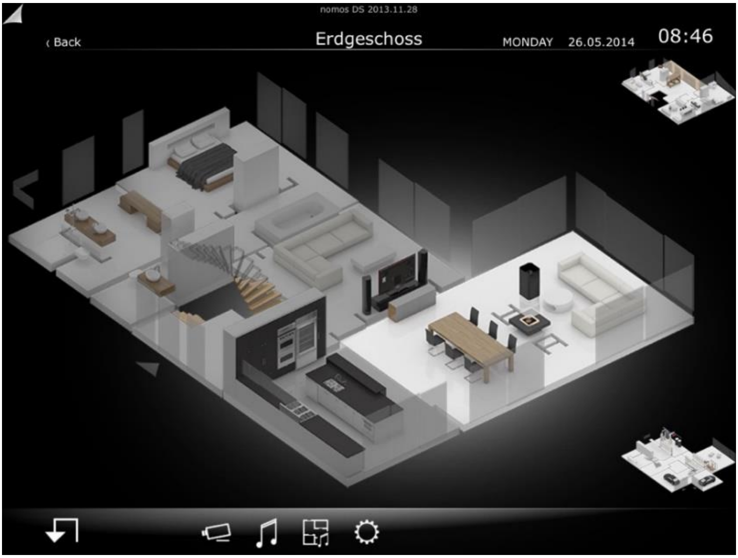

Figure 4-3: Screenshot of nomos' interface using a spatial metaphor (Permission granted by Michael Eudenbach, nomos)

4.3.3. Log List

Log list interfaces (see Figure 4-4) are usually included in the two interface types that are described above, and we list them for the sake of completeness as all three are based on the same underlying data. These lists are usually practical when the user is interested in **viewing the event history**, thus filtering for past events that happened within a specific timeframe.

The interface types described above suffice when the user is interested in changing simple settings or is able to properly specify what she is interested in before accessing the data. However, they are not suited for causal understanding of complex interactions between multiple devices and programs running within the smart home. This is mainly due to the lack of an appropriate way to meaningfully present interactions and interdependencies between devices, rules and the user that occur over time. E.g., in categorical menus the user cannot see patterns in the home's behavior across different functions, or different rooms; in spatial metaphors, it is difficult to see behavior over time and log lists usually contain a large amount of textual and numerical data that is difficult for end users to make sense of.

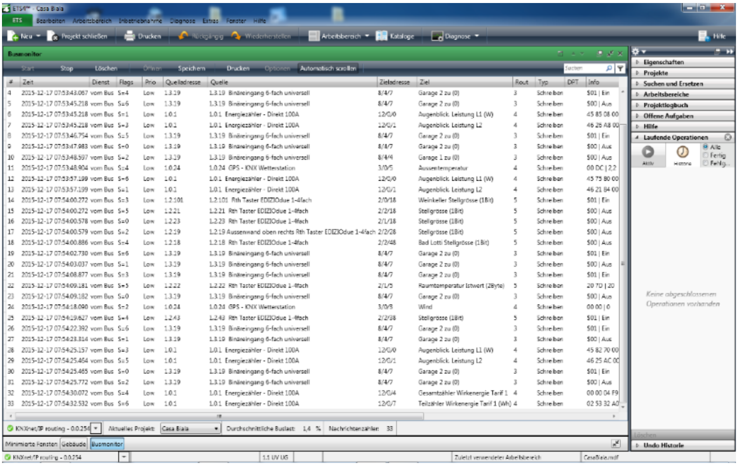

Figure 4-4: Logged events of smart home network communication (Permission granted by Michael Eudenbach, nomos)

There are further usage scenarios that are often overlooked but could contribute to a better inclusion of Passive Users through a more appropriate presentation of data across the entire home that we hypothesize will contribute to a better understanding of one's home, and will address several aspects that are problematic for some or all inhabitants:

1. Find the reason for an unexpected actuation of a device that has multiple potential sources in an easily accessible way
2. Discover new opportunities for automation and potential conflicts by detecting behavior patterns

3. Adapt the home's behavior to the user's own personal schedule (i.e. routines and exceptions, as opposed to manually overriding the program every time or putting up with a sub-optimal configuration)

The above-mentioned interface types are most commonly used in current interfaces for smart homes, yet are not ideal for addressing these scenarios, as they either require the user to already know which devices, category of device, or location they want to look for, or they isolate the various devices without the option to view multiple devices and their behavior in the same view.

4.3.4. Timeline

Often, automation in the home happens in several places at the same time or even uses event triggers that do not have a spatial physical location, such as time of the day or control through remote access. But they all manifest their effects at a certain moment in time. We found temporal interfaces provide a suitable metaphor, as all events in the home share that they are taking place at a specific time and people are used to dealing with timelines, schedules, calendars or clocks in their daily life. By visually retracing actions executed by the home (e.g. light turned on, shades drawn up) for multiple devices or functions on the same timeline, a single interface can provide a **temporal overview** of the patterns and behavior of the home. Routine and repetitive behavior, as well as exceptions thereto, become instantly visible and can provide indications for a potential **chain of causalities**. To improve this, they sometimes include information on the sensors that triggered them (e.g. brightness sensor). Low-level events could be given a semantic meaning and adapted to a user's schedule when the home's and user's calendars are integrated in the same interface. Prior calendar or timeline views are currently not used as the main smart home interface, but just for visualizing the data of a single device or function, such as heating or air conditioning as for example in the app of the home automation system Loxone (see Figure 4-5) or accompanying website of the learning thermostat Nest (see Figure 4-6).

Figure 4-5: Two ways how the Loxone App uses timelines in their mobile app: (left) showing temperature fluctuations through a continuous timeline; (right) showing temperature level and connected settings (Permission granted by Martin Öller, Loxone)

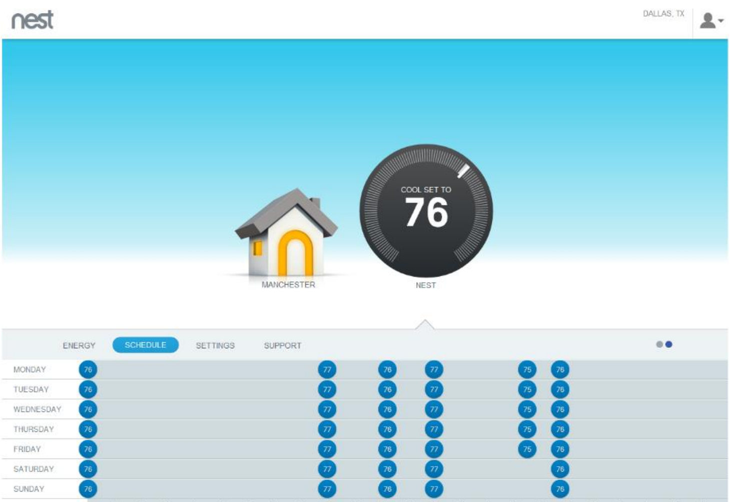

Figure 4-6: Screenshot of the accompanying website for Nest, a learning thermostat, showing the different temperature levels that the thermostat is scheduled to.(Screenshot from study by (Yang & Newman, 2013), permission granted by Rayoung Yang)

How well the various tasks are supported by each approach naturally depends heavily on the implementation of the metaphor. To give an overview of general tendencies for the suitability of each approach, we provide our rating in Table 4-1.

Table 4-1: Four types of prevalent interfaces for accessing and viewing smart home data

	Categorical Menu	**Spatial Map**	**Log List**	**Timeline**
Chain of causality			✓	✓
Glance-ability		✓ Current state of the		✓ Temporal patterns
View event history			✓	✓
Temporal overview				✓
Spatial overview		✓		
Direct access		✓		✓ Of devices with recent
Change settings	✓	✓		✓
View current state	✓	✓		✓

Among other factors, the type of feedback from the large amount of different services and devices can vary a lot. While categorical menus allow simple access to devices and the rules that they are set to, it is more difficult to use them to inspect a history of behavior in order to develop trust that the home was doing what it was supposed to. From the table it is easy to see that the current implementations of the various approaches do not support all types of interaction equally well.

4.3.5. Why Calendars?

We found that calendars, as a more elaborate and specific example of timelines, provide a promising research opportunity in the context of smart homes, to facilitate the understanding of a smart home's behavior and to align the behavior of the home more, in order to support its inhabitants' routines. Calendars:

- Provide an interface metaphor that is familiar to most users
- Are already commonly used tools of daily practices of families
- Can be used to express, communicate, or plan behavior and routines
- Are used to coordinate or manage conflicts with other people or resources
- Contain personal information about users that potentially could help identifying a family's goals, values, priorities or life style choices
- Can be used to access a history of information
- Have not been extensively investigated in the context of smart homes

These points led us to believe strongly that the metaphor of a calendar could address the requirements we defined earlier: help inhabitants to build an understanding of the home's actions, offer an interface that connects the routines of inhabitants with those of the home, that is accessible enough to be usable by all family members. We also emphasize that we explore the calendar metaphor not to create another isolated interface but to learn how it can contribute to existing user interfaces that are commonly in use to make sure that people can continue to maintain their current practices. Despite all the potential for calendars as an interface metaphor, we are aware that following a strict temporal metaphor approach introduces other limitations and might not be a suitable approach for all smart home components. Throughout this chapter we will point to these shortcomings and the ways we think they can or cannot be addressed.

4.4. Designing Casalendar

To evaluate the benefits and pitfalls of the calendar metaphor, we developed a concept for an integrated calendar interface which we called *Casalendar*. The basic idea of Casalendar is to represent the home in a calendar format, just like an individual's calendar would be shown, and alongside the calendar or calendars of the inhabitants. The various actions it carries out will be displayed as entries in it and provide additional information in each entry's detail to address use cases that so far have been not specifically addressed in smart home interfaces, and that participants of our study stated to be problematic, such as finding the reason for unexpected actuations, seeing patterns of the home's behavior, or spotting conflicts in case they deviate from their everyday routines. Additionally, we wanted to learn about whether people would see potential in being able to see a home's "plans" for the future, i.e. the events that it will or is likely to carry out, acting on the rules it is configured to.

To inform our design before creating an eventually deployable prototype for "the wild," we created preliminary versions in multiple iterations (see Figure 4-7): first, we created paper prototypes and an early interactive prototype to learn about participants' reactions to the concept of a home having a calendar and how this could be used for suitable feedback from a smart home. In our second iteration, we included the notion of controlling the home via a calendar, and in our third version of Casalendar we focused on the integration with participants' actual calendar information as well as live smart home data. In the remainder of this chapter we will describe these iterations, the design of our prototypes, our evaluations and the lessons learned.

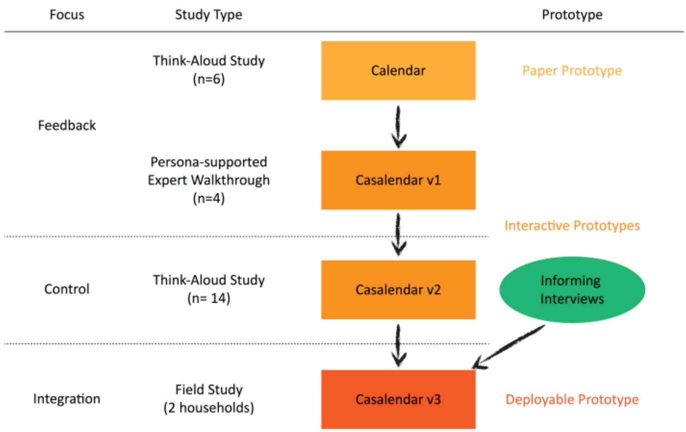

Figure 4-7: Overview of the iterative development of Casalendar

4.5. Casalendar v1: Feedback[3]

The focus of the first exploration of the calendar interface was learning about people's initial responses to having a home represented analogously to a family member in a calendar. For that purpose, an initial paper prototype was created (see Figure 4-8) which would show events for the smart home (left column) along with the events of hypothetical family members (other columns).

We choose to give home related events (smart home events) a simple representation similar to regular calendar entries in commonly-used digital calendars (yellow Post-its in the left column), i.e., they are shown as discrete blocks of time. However, instead of containing a textual description of the event taking place, we opted to use a simple pictogram description with one icon for a trigger or cause of the event and one

[3] Based on: **Mennicken, S.**, Hofer, J., Dey, A. K., & Huang, E. M. (2014). Casalendar: a temporal interface for automated homes. *In Extended Abstracts ACM SIGCHI Conference on Human Factors in Computing Systems* (CHI '14).

showing the effect of it, e.g. (a) in Figure 4-8 shows how brightness triggered the shades to be pulled up. The Post-its also contained a short textual description of this trigger-cause relationship that would clarify what the icons were depicting.

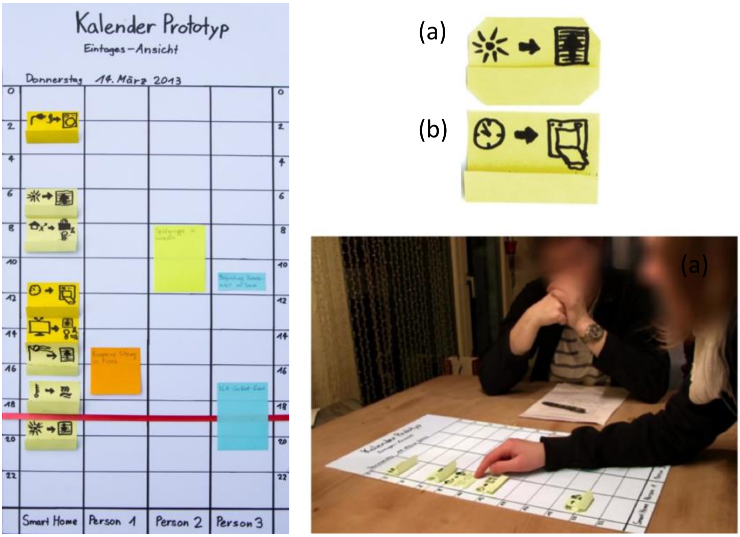

Figure 4-8: (Left) Paper prototype of calendar interface that incorporates smart home events; (top right) smart home events showing a trigger icon and an actuator icon; (bottom right) think-aloud study with a participant interacting with the paper prototype

4.5.1. Preliminary Evaluation and Implications

The paper prototype was evaluated in a preliminary think-aloud study (see Figure 4-8 bottom right). As our focus of this study is on Passive Users, we recruited six participants through our social networks that reported to have little to no technical background, did not live in a smart home and also had no specific knowledge about smart homes. Their participation was voluntary and not compensated. The age ranged between 22 and 57 years and we had an even gender split. The sessions, which took an hour on average, have been video-recorded and were transcribed afterwards. Besides catching issues with the interface design, our goal in this early study was to learn about whether participants understand the temporal metaphors we used to convey information about smart home behavior, whether they see any benefit in them, and how they envisage using them.

Integrated interface to turn to in case of problems

The preliminary evaluation indicated that participants understand the general concept of the home having a calendar and of events being automatically placed in it. Participants mentioned that they liked the idea of having an integrated interface, rather than a stand-alone interface for smart home interactions, as described by one of the participants: *"With the proposed prototype there is no need for explicit attention to automated [actions], but it could be checked if something is unclear."* This is one of goals we wanted to achieve by taking advantage of the familiar metaphor of the calendars.

Day view restricts identification of behavioral patterns

In our first paper prototype we only presented a day view to the participants, which would not allow people to easily spot routines or behavioral patterns of the home. We also found that the amount of information contained, for the participant as well as for the smart home, was still rather minimal. Thus, to move forward in our development and to be able to eventually display more representative content we decided to create an early interactive prototype.

Discrete event representation needs to be adjusted

While the simple visualization of the events was generally understood, it also introduced questions about the actual duration, e.g., whether an event marks the beginning of a new state, such as the shades going down at the starting time, or whether the end of the event indicates the reverse of the state, i.e., that the shades were only down for the duration of the event. This is interesting as even people's own events are not necessarily happening as they are described in the calendar (Lovett, O'Neill, Irwin, & Pollington, 2010).

4.5.2. Interactive Prototype

We revised the calendar design of the paper prototype, addressing issues identified in the paper prototype evaluation, such as insufficient differentiation between various event trigger categories and icons that were difficult to identify. We decided to develop a concept that could be deployed on a central touch panel screen as this is not only suggested by related work on calendar (Neustaedter et al., 2009), which found (pen-)touch based interactions to be better suited for calendar locations that are not on a desk setup, but also, simply, is commonly found in current smart homes. As our first focus was on mere information retrieval and simple access, we optimized our interfaces for finger-touch interactions.

The prototype Casalendar v1 was developed as a web application (see Figure 4-9) that takes data from a calendar server. Smart home events are gathered from this server as standard calendar events in the CalDav format (*CalDAV*, 2015) with additional information about which devices are affected by a particular event. In order to display the calendar view, the framework jquery-week-calendar (*jquery-week-calendar*, 2015) was used. This framework uses several JavaScript and jQuery libraries to display a HTML5 web page. Casalendar v1 was able to display actual personal calendar events from any calendar service that provides its content as an ics-file alongside simulated smart home events. However, this feature was only used to maintain several prefabricated versions of our prototype that contain different content for our user studies.

As opposed to our paper prototype, the standard view of Casalendar was a week view (see Figure 4-9) to allow people to spot repeating patterns of the home, e.g. shades being raised at the same time every morning. Calendar entries of events were shown in one column for each day, treating the smart home calendar just like any other calendar of a person. The color-coding was used to indicate who or which function an entry pertains to.

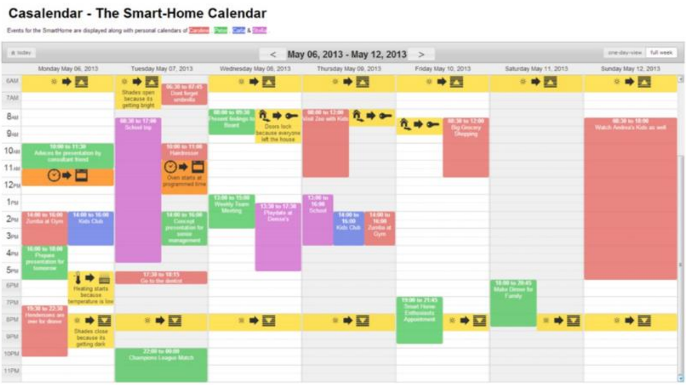

Figure 4-9: Screenshot of the first interactive prototype iteration

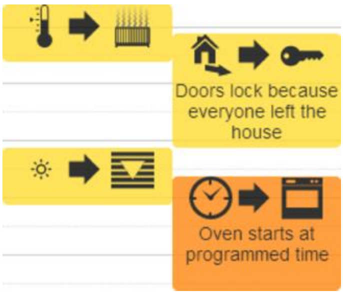

Figure 4-10: Interface detail showing examples of used pictograms and descriptions of smart home events

Just like in our paper prototype, all smart home events include two pictograms. One displays the cause of a triggered rule (such as a certain level of brightness or time of the day) and another pictogram shows the corresponding effect (such as shades going down or the heat turning on). In the interactive version, an event could be clicked to access additional textual descriptions (see Figure 4-9).

Evaluation

We chose to evaluate the prototype with four HCI experts before going into studies with actual smart home inhabitants as this would provide not only a faster iteration of our system but also give us insight into how well our prototype suits best practices in HCI. To do so each expert was given a sheet with questions to conduct a Cognitive Walkthrough (Wharton, Rieman, Lewis, & Polson, 1994). To gain insight into further weaknesses in our concepts from the perspective of our target user group, we gave the participating experts the family personas we developed based on our earlier work (see Appendix C). These described illustratively the goals the smart home inhabitants have and also their challenges, so that they could reflect their observations in that light. The experts were then evaluating the interface in pairs so that they could discuss it within the personas they were assigned to and provide their expert feedback from a user's perspective. E.g., they were asked to discuss why they would or would not buy such an interface or how it could be customized to meet their goals.

The experts used the interface on a touchscreen to complete simple tasks (e.g., navigating through the interface, retrieving information about specific smart home events). To achieve interaction conditions similar to wall calendars and match the size of calendars we found in participants' households for our study setup, we used a 20" tablet device (see Figure 4-11).

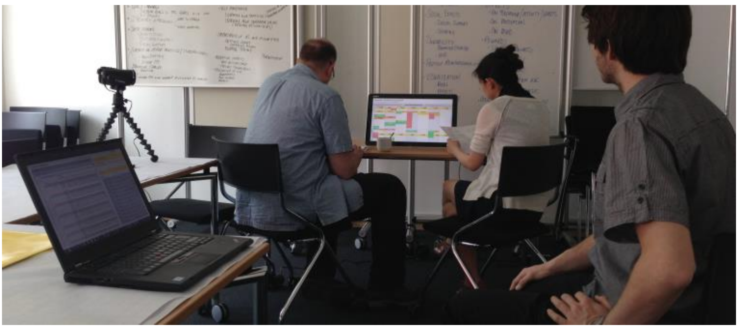

Figure 4-11: Experts during our cognitive walkthrough study using family personas

Results

Overall, the proposed visualization of smart home events as calendar events was well understood and seemed to match with the existing mental models of calendar tools. However, this was just a preliminary indication of the applicability of this metaphor as the interface content was still simple, compared to a complex smart home system "in the wild."

Visual distinction between home and people

The experts found that the number of colors used to identify the different types of smart homes entries restricted the functionality as a regular calendar. Due to the large variety of colors from smart homes as well as different personal calendars, the visibility of personal events was reduced.

Option for control

Besides several interface usability issues, mainly regarding the touch gestures used, the experts suggested that users would want to draw connections between personal events and the smart home's events. They expressed that inhabitants would want to have more options to change the visualized events. We took this finding as a motivation to work on these limitations of our prototype, but we also interpreted it as an indication, albeit still to be proven, that a simple visualization, like our calendar, could motivate Passive Users to more actively engage, increasing the minimal interest in control or configuration we found they had in our empirical studies.

4.6. Casalendar v2: Control

In our second iteration, Casalendar v2, we wanted to learn whether our modifications to the interface improved the understanding of the shown events, as well as learn more about the applicability for actual current smart homes by recruiting smart home inhabitants to this study as well. Based on the feedback on our initial prototypes, we created an updated version which also provided control elements for various functionalities within the calendar events (see Figure 4-12), to learn about the perceived limitations reported in our expert study. In this version we also included entries in the future such as events the user has programmed (e.g., a timer set to turn the oven on), or that might take place due to preconfigured rules in the smart home configuration (e.g., the expected outdoor brightness triggering the shades to close). We did so to learn about people's perceptions of predicted events in a calendar.

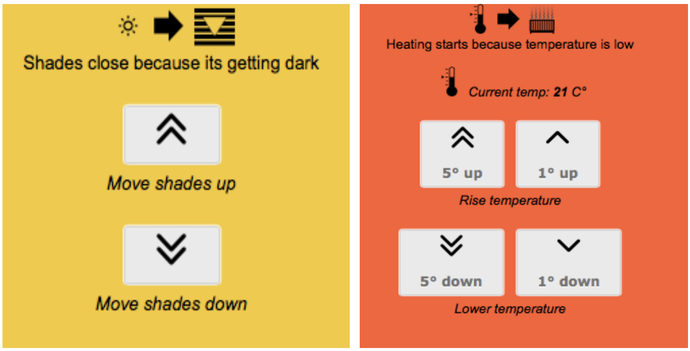

Figure 4-12: Details of the smart home calendar entries

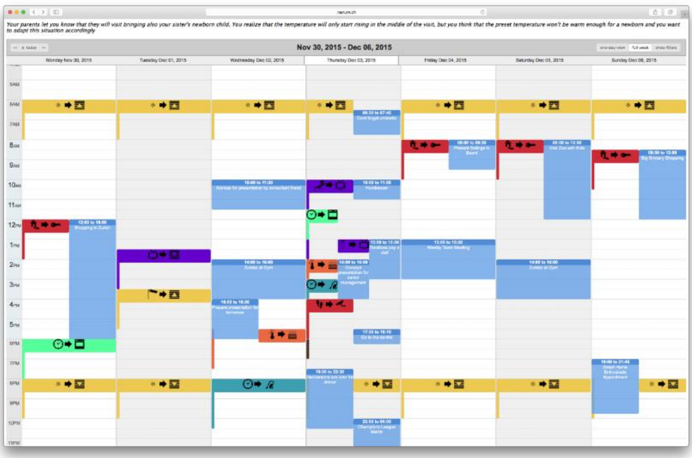

Figure 4-13: Casalendar v2 week view including the scenario description for study purposes

The updated prototype's standard view was still a weekly overview of the personal calendars of each member of a household. However, to address the problems of distinguishing them from the homes' events and reduce the visual complexity, they were all given the color blue (see Figure 4-13). Smart home events were color-coded by their functionality (e.g. shades, or security related).

4.6.1. Evaluation

We recruited six participants not living in smart homes (referred to as N1 to N6) as well as eight participants living in four different smart homes in Switzerland (referred to as SH1 to SH8). Two smart-home households were recruited via the established network to local smart home providers, while the other two households were participants of a previous study. All other participants were recruited via social networks of the researchers and a mailing list at the University. The age range of the smart home inhabitants was from early 30s to mid-40s, and three of the four households included children. The gender distribution was equal in both smart-home and non-smart home inhabitants. In all four households, the male participant was the primary administrator of the smart home, while the partner had less of a technical background. SH1 and SH2 participated in the study remotely, using screen-sharing and Skype. SH3-SH8 were interviewed in their home, while N1-N6 all participated in the study in our lab in which they also used the touch screen functionality of our prototype. Due to the longer duration of the study sessions that involved the interviews, SH1-SH8 received CHF 30 for their time, N1-N6 did not receive an incentive beyond snacks offered after the session.

In the interface walkthrough, we asked participants to use our interface in seven different scenarios we created for five typical smart-home functionalities (automated shades, heating control, vacuum cleaning robot, motion-triggered webcam, and programmable oven). While they all could be related to specific devices or functions in the home they were phrased around usage scenarios of the inhabitants, e.g. *"You just got a notification on your phone: your alarm system has sensed a suspicious movement in your basement. Now, you want to check this suspicious movement with Casalendar and decide your future actions"* or *"Because of some urgent tasks you have to start* *work half an hour earlier for the rest of the week and thus, you will have to wake up earlier. You would like to adjust your shades in the morning to reflect that change in your routine."* We created most scenarios from experiences that participants reported on in our initial studies. A few of them we created in a way to learn about participants' mental model of functionalities whose effects might be less transparent or immediately perceivable such as our heating scenario: *"Your parents let you know that they will visit bringing also your sister's newborn child. You realize that the temperature will only start rising in the middle of the visit, but you think that the preset temperature won't be warm enough for a newborn and you want to adapt this situation accordingly."* To learn how reasonable those scenarios were, we asked the smart-home inhabitants whether they consider them to be realistic for their own home.

4.6.2. Informing Calendaring Interviews

In our empirical work, we did not observe any calendar usage specifically for the home. However, informally through posts in online forum interest groups as well as smart home-related blog posts we learned that there were instances of such an integration in use. Thus, we decided to also conduct a formative, semi-structured interview with the participant smart-home inhabitants about their current calendar usage, with a particular focus on whether and how calendars are used for coordination or communication between different members of the household. To ground the interview in current practices and to better understand how participants' calendars might interact with their smart-home experiences, participants brought their family calendars, physical or digital, to the interview. We encouraged them to refer to their calendar throughout the interview and to share one or more pictures or screenshots of their calendar with us ahead of time so that we could review them before the interview. The questions in this section focused on understanding what kind of entries they make, what determines what they put in their calendar and whether they kept any other tools to manage their routines (see Appendix D.2). We also asked participants about their experiences living in their smart home, such as how they control and configure their home and what actions it performs automatically on a daily basis.

4.6.3. Analysis

We audio-recorded the sessions and during the interface walkthroughs, we also recorded the screen. We partially transcribed the recordings and created 150 notes on participant quotes and our observations from the screen recording. Using a prototype application from our group's on-going research on Affinity Diagrams which provides a visual overlay and search within the notes (see Figure 4-14), two researchers created three levels of groups based on these quotes and observations, resulting in the conceptual themes we report in this chapter.

Figure 4-14: Affinity diagram with visual augmentation of the PapperlappApp prototype

We first describe what we learned about how people currently use calendars to coordinate family life. We then delve into the findings we identified in trying to apply the calendar metaphor to this problem space. In particular, how a calendar-based interface can improve smart-home intelligibility, promote mutual understanding between home and inhabitant, unify scattered interfaces, coordinate devices, and better support both family routines and values. We also identified gaps between our calendar-based interface and participants' mental models, notably in terms of participants' expectations of content, how the system presents multitasking, and the uncertainty of future events.

4.6.4. Findings and Implications

In this section we report the results from the data collected in both, interface walkthrough as well as informing calendar interviews along the themes that emerged.

Personal Calendar Usage

In all smart home households we interviewed, calendars were used not just as a reminder tool for individuals, but for coordination and communication with other family members which confirms previous findings (Neustaedter et al., 2009). For example, calendars were the channel for informing all household members about a decision that affects the family, like allowing the children to schedule an event on a weekend or denoting times when specific household members would not be available *("If I might think he would be at home at 7.30pm but he won't, he will put an event in [our shared calendar]."* (SH3)) Our participants conceived calendars as a tool to coordinate with people not just in terms of time, but also to allocate shared resources. For example, SH2 noted in the calendar who could use which car on certain days to mitigate potential conflicts.

Although all participants used family calendars for coordination and communication, they did so in very different ways. In two households, both partners used digital calendars exclusively, because they facilitated communication. In the other two households, only the husband used a digital calendar — mostly for work — while the primary family calendar was a physical paper calendar centrally located in the home and managed by the wife. Her role as a *primary scheduler* was a common pattern for those calendars as found by Neustaedter (Neustaedter et al., 2009) and promising for our plans to integrate the smart home into this central tool. The paper calendar contained events that concerned the whole family, and synchronization with the digital calendar was oral. Calendars in the two households in which both partners used digital calendars contained more entries than the mixed households. In the households that relied on a central paper calendar, recurring or routine events (e.g., weekly participation in hobbies) were only written on the calendar if there was a deviation from the usual times or following periods of frequent deviations from routine (e.g., a reminder following a holiday break (SH3, SH7)).

Most participants stated that they rarely put general to-do items that lacked a specific due date in their calendars because they either used other tools (e.g., dedicated apps on the phone) or physical reminders (e.g., paper checklists). However, in their calendar photos and screenshots we did observe several instances of calendar entries with specified times that were general to-dos without a particular temporal schedule, which aligns with prior work (Lovett et al., 2010).

The two families who used digital calendars as their family calendars already had their family's schedules in a form that could integrate with the smart home. The two families that still used paper calendars valued having a centrally located, visible space for coordination and communication, which is also one of Neustaedter's findings (Neustaedter et al., 2009). We hope that developments for improved ambient calendar displays and the ability to better coordinate with the smart home might encourage these families to similarly switch to a digital interface which is one of the underlying requirements for the concept that we are building in Casalendar.

It is encouraging for the idea of using a calendar metaphor for smart homes that families already note exceptional and non-routine events in their calendars, potentially enabling smart homes to automatically determine when an action might be inappropriate in light of the family's events. However, families often neglect to place routine events in their calendars, which would make it more difficult for a smart home to automatically craft initial programs that align with family members' schedules in a bootstrapping process.

Existing Problems in Smart Homes

As to be expected, participants reported on issues with their home that we identified in earlier interviews, too. For example, one strong emerging theme was again that their least favorite aspect of their smart home was the initial phase of configuring the automation rules and reiterating them until reaching satisfactory automation. As SH1 described, *"the most painful period [was] the beginning, when it wasn't refined yet."* Participants noted that this process is cumbersome and can take a long time, confirming our findings presented in Chapter 1 as well as those of other researchers (Bernheim Brush, Lee, Mahajan, Agarwal, Saroiu, et al., 2011b).

Mutual Understanding

Our participants would have preferred that the home learned on its own what should be automated. P4 explained this concept as a desire for *"the home [to be] much better at finding [behavioral] patterns for automation."* In essence, participants wished the home would automate itself based on the inhabitant actions it observed, as well as the interdependencies between actions. This would leave the user with only the task of confirming or adapting a new automation rule. This desire also extends to future events, for which the home would present the user with its own predicted understanding of what will happen based on prior observations. Predicted smart home events visualized next to personal calendar events could help users spot the necessity of an exception or adjustment of an automated behavior. In our study, two households reported how they sometimes forgot to disable automated functionalities in their guest rooms (such as shades going up in the morning (SH2) or lights being controllable only by motion sensors (SH4)). They reported that they would turn it off so that guests would not be disturbed by the automation and would be able to control their room in the way they were used to. Again, rather than providing the home with detailed instructions up front, a user would only have to confirm the home's understanding of automatable behaviors. In the case of SH2 or SH4 the home could propose to deactivate certain functions when noticing that a calendar entry indicates that guests are staying overnight.

The home is expected to be much better at finding opportunities for automation.

While current smart homes remain far from that vision, we believe that calendars can potentially transform typical one-way command interactions into a two-way communication and eventually a dialog. Currently, inhabitants have to go through rather illegible log files in order to see how the home senses activities. People interested in technology, such as SH6 and SH8, reported doing that. However, this requires the inhabitants' motivation and additional effort, as it is separated from the tools they use in their everyday life. Calendars are used on a daily basis and are well understood. Smart homes could use them as an entry point for gathering data about users' routines and merge it with the home's "routines." If the smart home notes both past and anticipated future actions on the calendar, along with why it is taking

Rather than having to provide detailed instructions, propose a solution and have user confirm.

those actions, the smart home's patterns can become visible and more intelligible. A home that could support the inhabitants this way would also fit into the vision of collaborations between humans and inhabitants that we described in 2.3.3.

Scattered Interfaces

While only one participant (SH2) attempted to control his home using his personal calendar – by preheating his coffee machine if he had a meeting at home scheduled in his calendar – participants from all households described how individual devices within their smart home already had time-related features, such as calendars, schedules, or timers (e.g., holiday schedules for shades and timers for the HVAC system). However, participants said such temporal features are scattered across devices, making it difficult to get an overall picture of the many-siloed schedules, such as shades, lights, or the phone, that could all be set independently to create a wake-up alarm.

Multiple devices of the home use calendars, schedules or

Participants who lived in a smart home reported that they considered their daily life too "messy" to be programmed in static rules, because of the need to handle exceptions. For example, automated shades that provided value in their regular morning routine created a hassle when the children were sick (SH8) or had a day off from school (SH5). As we found in Section 3.3.1 (The Understandings of "Smart"), a home is considered to be smart "if it fits the routines and avoids additional work." A home that cannot be easily adjusted to fit the routines, or to match the exceptions in such a way, therefore will not be considered to be smart. If the interface would contain the right scheduling information for coordinating these potentially conflicting events, a calendar-based interface could know to override the normal program or allow people to easily adjust it.

However, participants also expressed concerns about such an interface containing too many events and thus becoming overly cluttered. Surprisingly, participants who did not live in a smart home did not express these concerns; instead, they frequently expressed interest in integrating even more information (like N2 who wanted to include information such as power consumption of his PC and power sockets in the home). As found in prior work (Bernheim Brush, Lee, Mahajan, Agarwal, Saroiu, et al., 2011b), people often start with a highly configured home, using a lot of sensing and actuation, but iteratively simplify their setup. Our participants who had lived in their smart homes for a longer time (like SH3 and SH4, who had done so for over 8 years) reported enjoying automation for their morning and evening routines, but had created means to allow for potential exceptions by being able to easily enter a manual mode and override automation. A simpler, more transparent configuration would be easier to handle and while several potentially automatable actions would still be carried out manually, it would reduce the amount of exceptions the inhabitants had to deal with.

Complex configurations were often simplified with easier more manual controls to deal with exceptions.

Notably, as found in our earlier work in Chapter 3 as well, access to the configuration interface was often restricted to only one household member because the necessary software was only installed on the husband's computer. In addition, many of these interfaces were designed for users with a technical background. This situation made handling exceptions difficult or impossible, leading to feelings of frustration. For example, in a configuration in which shades always went up at a specific time in the morning, only the main administrator of SH5's home had access (and enough technical expertise) to change this configuration using a specific tool when they wanted to sleep in on a holiday.

Coordinating Devices

Temporal dependencies are not visible across the multiplicity of devices and services. SH4 and SH6 described how various technologies in their home, like shades, heating, and the weather station, have different configuration interfaces. A central interface, such as a calendar, could better unify access to these devices and provide greater transparency for all members of the household. That said, we found that participants also preferred to have direct, in-situ control of devices that require physical interaction (e.g., putting dirty laundry in the washing machine or food into the oven) stating that turning to a separate, remote interface added to their workload for simple tasks. However, the time-related functions in various smart-home interfaces should be unified. SH5 and SH8

Interest in interfaces that merge available information while maintaining in-situ controls.

expressed special interest in having remote access to a unified interface for changing the oven's timer function, for preparing meals for their children.

Mental Models

Leveraging a familiar metaphor, such as a personal calendar, can help people to understand interfaces better, but some aspects might not transfer well. In this section, we unpack participants' reactions to our prototype calendar-based interface in light of how they said they already use calendars for coordination and communication.

Expectations of Content

Participants expressed that they did not know what to expect from the calendar entries of a smart home or what they might be able to do with them. They further wondered what information they could expect in the "detail view" of a home's event. They reported that personal calendar entries usually serve as a reminder for themselves to be somewhere at a specific time, whereas we intended for calendar events in our prototype to be a means for communicating about a home's actions. They also mentioned that typical calendar events mostly occur away from home. Thus, typical calendar events sometimes contain information like a location or directions. This understanding did not transfer to our prototype's entries from the smart home.

Calendar entries were understood as reminders for the inhabitant to be somewhere or to do something.

This strong understanding of calendar entries being reminders to the users made participants wonder whether the home's entries were actually something the user herself had to do, as opposed to a visual entry of the home doing something. For example, SH7 wondered whether the prototype's entry with the vacuum cleaning symbol meant that the home would vacuum at a specific time, or whether the home requested that the user vacuum at that time *("Oh, so I'm planning to vacuum clean at 8pm […] or is it the robot vacuum cleaner?"* (SH7)).

Multitasking

Another theme that emerged from our data was that participants perceived entries in their calendar as duties for a single person. As one single person cannot attend multiple events concurrently, multiple

While multiple smart home events at the same time are likely, they could be misunderstood as conflicts.

entries listed at the same time imply a conflict. E.g., SH5 described how they set up individual calendars for each of their children to easily filter individual events and spot potential conflicts. However, multiple entries in our prototype interface at a single time were not just plausible but likely, because a home would often actuate multiple devices at the same time. For the smart home, concurrent entries do not necessarily imply conflict.

At the same time, simultaneous events in a smart home may or may not be related to each other. Participants stated that they would want the home to highlight actual conflicts to reduce visual complexity and make them more aware of where to focus their attention (SH1, SH3). For instance, an actual conflict might occur if the smart home instructed a device to be in different states at the same time. The calendar-based interface could be refined to highlight those kinds of potential conflicts.

Future, not past, Events

All of our participants used either a monthly or weekly overview in their own calendars. Those who used a digital calendar noted that they would access the details of individual events for more information. They consistently stated that they used their calendars to plan events and schedules in the future. Notably, they reported to rarely look at past events.

The focus on future events in personal calendars could compromise a seamless integration of past smart home events.

In contrast, we designed our interface to display both the smart home's (logged) past actions, as well as anticipated future actions. We intended for the past events to provide insight about why the home had reached a certain state, providing transparency to all inhabitants of the smart home. Especially those participants who did not configure the home themselves, appreciated the eased access to information about the trigger for a specific automated behavior, for example, information on the sensor that caused the shades to go down. However, in light of our goal to seamlessly integrate the smart home's actions with its inhabitants' routines, participants' tendency not to look at the past might present a challenge. If people tend to focus on the future, information in the past might not be relevant enough for them to capture their attention.

Future Events' Uncertainty

We had created several scenarios around the idea of whether anticipated future events could be used to identify potential conflicts with upcoming personal events (e.g., seeing the scheduled actions of the vacuum cleaning robot only after an entry about a visit by relatives). Almost all participants raised concerns about the feasibility of heating scenarios, since *"it would take a lead-time of 24 hours with our heating system; I'd rather just open a window,"* as described by SH3. SH1 mentioned, though, that it would be interesting if she *"could configure such effects in the calendar entry, like location information [in regular calendar entries]"* to plan for the home while planning for herself. This comment was also a promising comment for the potential of the smart home calendar as an integrated tool in which interactions with the home would become part of the calendaring routine.

However, future calendar events are only predictions, even for traditional family calendars. They may take place earlier or later than scheduled, have a longer or shorter duration, or not take place at all (Lovett et al., 2010). The same characteristics apply to the smart home's predicted future events. While some triggered events are dynamic, yet possible to predict with some accuracy, like weather, temperature, or brightness, other sensors (e.g., motion sensors) can be difficult to predict even in households with very regular routines. Unfortunately, participants found this uncertainty confusing in the case of the home. When looking at the future events of the home, participants wondered if those events would really stay like in that schedule, or whether the smart home would change them (SH6, SH8). This is especially interesting for the questions we are addressing in the next chapter in which we explore the perception of proactivity and agency in homes.

Uncertainty of future smart home events that are based on sensed data confused people.

Supporting Routines and Family Values

A persistent dilemma in the transition to smart homes is that the benefit of automation is limited if inhabitants have to check whether it has been carried out. For example, SH1, who has been living in an automated home for four years said, *"If I have to check on the calendar it would mean I don't trust the home. That doesn't make any sense."* A truly smart home would be able not only to support its inhabitants' values and routines, but also

Having to check on the home compromises the support and derived value of automation.

catch deviations. Unfortunately, current smart homes simply are not that smart. However, this check could be facilitated. For example, a calendar could provide the user with easy, optional access to information about what the home has done in a familiar interface by visualizing when configured rules were triggered. To make this useful to the inhabitants, such a visualization also needs to provide the means to make this information actionable. N4 expressed wanting to have access to an overview of all configured rules that a visualized device is involved in, so he could change them if needed.

Existing Smart-home Calendars

Personal calendars contain home-related events, but rarely utilize smart home functions.

As mentioned earlier, only SH2 reported using his calendar explicitly for controlling a function (a coffee machine) in his smart home. He discontinued this program, however, as the coffee machine was heating more often than actually needed. However, several other households added events related to maintaining their (non-automated) home to their calendars. For instance, participants wrote reminders to fertilize the lawn and check their heating systems at a specific time of the year. These events could provide additional data to help the home understand a family's desired automation.

Invisibility of Changes and Delayed Commands

Behavior of the home varies over time due to seasonal configuration changes.

Calendar entries can also support trust and accountability by providing an optional source for feedback. A smart home develops iteratively over phases and often has to be set to different configurations depending on the season, as remarked by SH8: *"What's going to be of interest in the summer will be the shading functions, but [my partner] has to reprogram that first."* This development often implies that users have to update their understanding of what their home does automatically. If the home was not configured for them, new smart-home owners first have to make sense of new sensor data and think about what their home could do for them with that information. SH6 noted that he had to observe how the weather in their location affected the brightness sensor in order to adjust its sensitivity so it would correctly trigger lights and shades.

In our interviews in the Casalendar study as well as our informing interviews, participants frequently mentioned that they wondered whether the home actually carried out the action it was set to do. They reported that the calendar-based interface could help them to get an overview over the home's actions that increased their trust in the automation. However, the representation on the calendar would still not guarantee that the physical device was actually in the expected state. Similarly, though, in traditional calendars, a calendar entry does not necessarily imply that the action was carried out (Lovett et al., 2010). Regardless, our participants expressed a somewhat misplaced feeling of trust in the smart home's calendar entries.

Overview of the actions that the home carried out could increase trust.

Communicating Changes

Smart homes are often initially configured by an individual, sometimes even by an external technician – such as in SH6's case, who hired an electrician to set up a working basic configuration right after they could move into the new home. He was then planning to extend it later. SH4 explained further that there were different ways to configure the same behavior (e.g., lights could be restricted to only be activated by motion at certain times. This could be set by restricting the light actuator itself or by restricting the triggering sensors). Different people follow different conventions for their configurations. Thus, the configuration is often not transparent. Furthermore, any update to the underlying configuration carried out by an individual is usually invisible to other members of the household, and it often requires access to a specific configuration tool that not all household members can access. P5 reported how she had to ask her husband to change the desired temperature for the heating last winter because she did not have any means to control this function anymore.

Even though the configuration of a smart home affects all inhabitants, several household members are disenfranchised from being able to contribute to the home's setup. While the calendar interface would not be suitable to preemptively display changes of the underlying configuration, it could offer a familiar interface for people to turn to in case they want to learn more about an event that just happened. SH3, SH5, and SH7, all partners to smart home enthusiasts, particularly noted that they liked the feature of our prototype which would allow them to understand whether the shades were dragged down manually, by brightness triggers or because of too much wind. Finding this positively noted by the Passive Users makes us confident that this feature could be useful for people without a technical background to build a better understanding of the inner workings of their home.

An accessible tool could provide a means to communicate desired, as well as conducted, changes to the home's configuration.

The understanding that a calendar is a communication tool could be applied to the home and leveraged to incorporate the smart home into family coordination. The calendar could be used as a way to communicate what the inhabitant can expect from the home and its behavior, while the calendars of inhabitants can provide additional context to express what is important to them. SH5 commented that such an interface would allow her to show her husband the unwanted automated behavior and have concrete proof that *"the shades went up and down all afternoon,"* and also have a more tangible way to express what it is she wanted to have improved.

With a more familiar tool at hand, all inhabitants could mark or comment on events on the calendar that they perceived as "incorrect" behaviors. This could be used to either implicitly train the home or to communicate decisions to other family members. SH4 suggested: *"Put in a note why it was necessary [to change the configuration], so that I can take a look at it when it's of interest – a month later or a year later […] There might be several people in the household, and so the others would see, 'Oh, that's why he configured it that way'."* Similarly, SH5 wanted to be able to have a history of notes to derive a mutual decision before carrying out *"changes to more serious functions like heating."*

Need to Understand and Support Family Values

Content of the calendar could provide the home with information about a household's values.

We described in Section 2.3.1 (Meaningful Technologies) that having smart homes support family values, goals, and routines as well as their implementation in everyday life instead of providing individual functionalities, is an ongoing topic of research interests. The kind of events people entered in their calendars could potentially help the home understand the values of the family. For example, in one household both partners created a weekly "date night" event on their calendar in order to make sure they spent enough quality time with each other. They reported that they even disabled the doorbell during that time. This action could be set automatically by the home if it knew about the event; it thus served as an example of how the context of family events could help support a family's values.

The home could also be a supportive environment in terms of helping people maintain their daily habits, if so desired. In one scenario, we asked participants to use our interface to prevent the shades from going down as programmed because guests would still be around. One participant wondered whether he might actually consider the shades going down to be a good thing, as it could politely imply, *"Guests, you've been here long enough now. It might be time to go back home now"* (SH6). SH8 expressed how she likes that her child *"by now knows that when the shades go up, she has to get up, too"* and that this way they learn and keep their daily routines.

4.7. Casalendar v3: Integration[4]

Building up on our understanding from our informing lab studies, we developed our prototype, Casalendar v3 (see Figure 4-15), which would allow us to collect insights about the everyday use of our concept in real homes. In our final iteration our focus was to develop a version that could be tested with participants' actual calendar data as well as show the real data that their home logged in a unified interface.

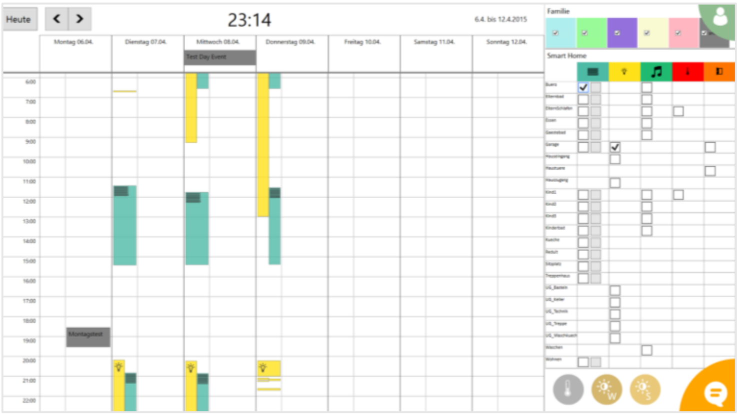

Figure 4-15: Casalendar v3 weekly overview

4.7.1. Design Changes

In our earlier lab prototypes, the mockup had several features that we were not able to fully implement in the deployable prototype, such as determining the root cause of certain events with absolute certainty. For instance, the actuation of shades in the participating homes was determined by a complex decision structure involving a weather station whose internal logic unit we could not access. Direct control of devices through our interface was somewhat limited, as it would not have been

4 Based on: **Mennicken, S.**, Kim, D., & Huang, E.M. (2016). Integrating the Smart Home into the Digital Calendar. In *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI '16).*

feasible to break apart the existing smart home configuration and reprogram all involved sensors and actors. Due to the complexity of this task and potential liability issues that could result from a breakdown of our research prototype, we decided to do this for only a limited subset of the home's functionalities. To make up for this restriction and to elicit further data on active usage, we allowed users to create "fake events" and record short audio clips that let them express their interest in particular smart home features missing in Casalendar. We also could not explore questions of smart home agency in our prototype as calendar entries from the home were either logged, placed by the participants, or future but static events.

Based upon Neustaedter's work (Neustaedter & Bernheim Brush, 2006) we attempted to incorporate many features and characteristics of digital family calendars that facilitate the adoption of the calendaring routine and the awareness within the family. However, we were not able to address all of them.

- Public & Accessible: This we achieved by developing our software for an unlocked Touch PC that was located in a position accessible to all family members.
- At a glance: The first calendar screen the user saw provided an overview of the whole week.
- Appropriate Info: By offering the options to filter for specific functions, we attempted to allow the user to customize their view to match their interests. However, the appropriateness of our choice of representation is part of the study interest.
- Work Access: In the current state of our prototype, participants did not have access to the smart home information outside of the home.
- Mobile Access: Our first design had the focus to present all information at a glance and was therefore not easily transferable to a small-screen device.
- Multiple Home Locations: For our first exploration of our prototype we only provided our interface on a single touch PC.

Providing an always-on interface was another aspect that Neustaedter (Neustaedter, Bernheim Brush, & Greenberg, 2007) suggested for digital calendar interfaces. However, participants of both of our households expressed concerns about the energy consumption and being bothered by the emitted lights of the displays in the evenings. Thus, we implemented a feature to dim the lights after a certain amount of inactivity.

Dealing with Visual Clutter

A potential danger of providing a one-week overview of events across multiple devices of the same and different types, in addition to personal calendar events of household members, is visual clutter and information overload, which would defeat our purpose. Therefore, we allowed users to view personal events of only certain household members and entries of specific types of devices in specific locations, which they could select with a filter panel on the side of our interface (Figure 4-16 (right)). We anticipated different viewing preferences for each participant and therefore added a one-touch login mechanism (Figure 4-16 (left) that allowed each household member to identify themselves, to retrieve and store their individual view settings. A future version could incorporate an automatic face-recognition-based login mechanism to simplify the identification process further.

Figure 4-16: (Left) Each user can retrieve a tailored view of the smart home data via one-touch login; (right) smart home and personal calendar events are shown side-by-side on each timeline and users can filter entries based on the device category and location.

Representation of Smart Home and Inhabitants' Entries

Our initial design treated the home's and the users' personal calendar entries equally in the graphical layout and arranged them within the same daily timeline. In the previous iteration we changed the color coding to make this more easily distinguishable. However, participants in our previous study reported wanting the color-coding for their personal calendars to resemble the calendar applications they were using before our field study. As we knew that this might again confuse our participants in distinguishing between home and inhabitants, we adjusted our design to arrange the smart home's events in the left third of the timeline and household members' personal events in the remaining two thirds of the timeline as shown in Figure 4-17. Our prototype now also emphasized personal events more, as to recreate a family calendar, which had the additional benefit of providing integrated access to additional information on and control of the smart home.

We preselected a set of sensor and actuation devices that should be displayed on the calendar, based on their importance and potential impact to the inhabitants of the smart home. Our selection included: window shades (turquoise calendar entries in Figure 4-18 (left), lights, sensors detecting the door/window state (as open or closed), heating, temperature, brightness, music player and a vacuum-cleaning robot. Discrete events and data are visualized as rectangular blocks (e.g. shades down or door open) whose size depends on the duration. Continuous sensor data such as temperature and brightness are displayed as graphs that span the entire timeline (blue graphs in Figure 4-17).

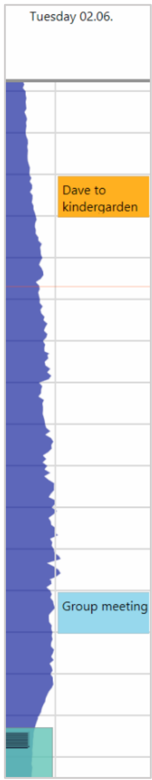

Figure 4-17: One day of the week overview, left third for smart home events, right two thirds for personal events

Figure 4-18: (Left) temperature graphs and shade events in Casalendar v3; (right) details of a light event

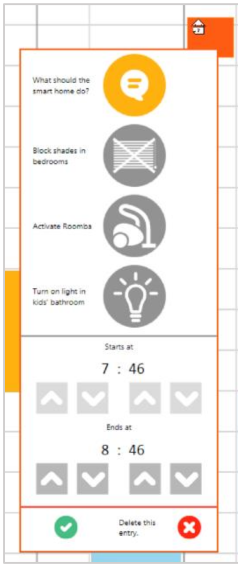

Figure 4-19: Details of a fake event

Our interface allows inhabitants to retrieve additional details of an event, such as a list of possible causes that might have triggered it, the exact duration of the event (Figure 4-18 (right)) and other contextual sensor data (e.g. brightness and temperature). To elicit usage data beyond consumption of information, we allowed inhabitants to perform simple control actions, such as locking specific motion-triggered lights or controlling their vacuum-cleaning robot directly through the calendar entries (see Figure 4-19).

4.7.2. Implementation

We deployed our prototypes on 23″ all-in-one multi-touch PCs that allowed users to access the calendar interface comfortably via touch. The smart-home infrastructure of our participants used KNX (*KNX*, 2015), a standardized network communication protocol for smart home devices that is used commonly and predominantly in German-speaking countries. To easily communicate with KNX, we used a software controller called nomos System (*nomos system*, 2015) which can be installed on a Raspberry Pi mini-computer and facilitates retrieving messages as well as sending commands from or to the connected KNX devices. The nomos device was then connected to the home's network at the router and was able to log KNX communication as well as sending out commands. In our first software tests that used actual smart home logs we learned that our HTML5 prototype would be too slow to handle the amount of data occurring over a longer time and that multi-touch processing (e.g. for scrolling) would have been restricted. Thus, the deployable prototype was built from scratch in C# and WPF. It further allowed the import of iCal streams from our participants' personal digital calendars so that they could continue to use the digital calendar they were used to and see their events updated in Casalendar.

KNX is an example of a "decentralized" home automation infrastructure, which means that the rules it acts upon are not stored in a central "unit of intelligence" such as a server, but in the individual devices. Messages are broadcasted on this protocol and upon retrieval the devices evaluate whether and how to react to them. A special KNX-licensed software is needed to change the configuration and upload those changes to the devices. This protocol was adopted by many of the big electrical providers such as Siemens, Bosch and ABB in the German-speaking countries as the distributed intelligence of such networks offers more robustness against blackout of a single point server. However, the broadcasting characteristic made it more difficult to create additional logic using our interface. To give participants an idea of how advanced control could look like through a calendar interface, we had to intercept the communication between certain sensors and actuators to let our system handle the logic for relaying digital messages and commands. But in such cases, the connection would be broken if our system crashed. In general, research software is neither engineered for maximum stability nor extensibly tested. Thus, it is not easy to be deployed as a critical part of a highly complex system, especially for a longer period of time.

To maximize stability to the best extent possible we used the following system architecture (Figure 4-20). We split our prototype in two key components: CasaCore and Casalendar. CasaCore is a component with minimal functionality that was simply responsible to connect sensors and actuators as they were setup before the deployment of our system. We kept the implementation as basic as possible and tested it thoroughly in the lab to feel confident about it being able to run the whole duration of the study. Casalendar included the front-end, the mechanisms to visualize the logs and import the calendar and any logic for controls that users could place in the calendar. As long as Casalendar was running, CasaCore would look up whether there were any user-created changes active that would, for example, block the actuation of a device. If Casalendar crashed or was not running, CasaCore would simply make sure that the events continued to be properly routed as in the initial home configuration. We found this architecture helped us in reassuring our participants that in case of a failure of the interface, their home could still be used and would behave as it normally would. This architecture also allowed us to reuse code from our software in a lab prototype that we present in Chapter 5.

On the KNX bus messages are broadcasted to group and contain a group address (e.g., 1/2/3) and a value (e.g., 1). In the configuration software, communication ports of devices identified by a physical address (e.g., 1.2.3) can be associated with a group address, which is also called communication address. Then messages that are sent to that address will be received by all those communication ports and they will react according to the configuration that was deployed on them.

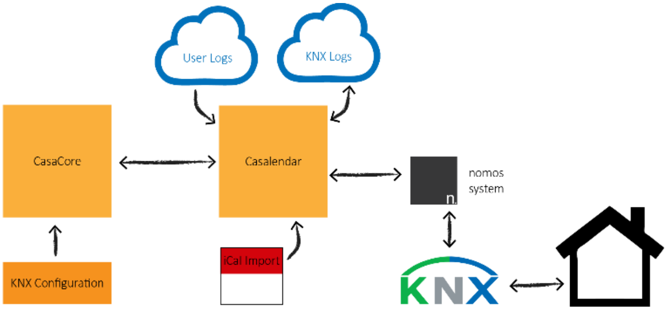

Figure 4-20: Casalendar's software architecture

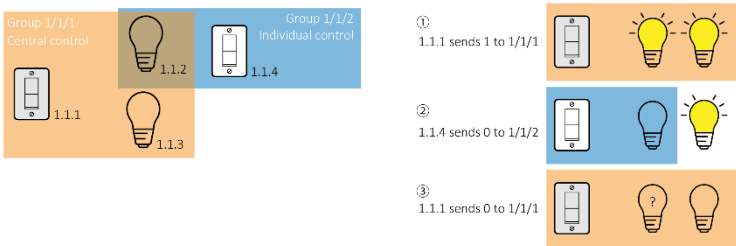

Figure 4-21: Example for a message sent across the KNX bus

To give a more illustrative example, group 1/1/1 is a central light function and contains a light switch (1.1.1) and two lights (1.1.2, 1.1.3) in the living room (see orange box in Figure 4-21 (left)). If the switch is actuated, it broadcasts a value, 1 for on and 0 for off, to the lights, which will cause the lights to turn on or off. However, a light can be part of multiple groups to not only be controlled via a central switch, but to also be controlled individually or as part of a scene which involves one or more other devices. In the example, light 1.1.2 is connected to the central switch (1.1.1.) and to switch 1.1.4 through group 1/1/2 that is an individual control function.

To provide an example of what KNX communication we would monitor (see ①②③ in Figure 4-21 (right)):

1) Someone turns on all lights using the central function.
   We monitor that 1.1.1 sent a 1 to group 1/1/1.
   Both lights are on now.
2) The individual control switch turns light 1.1.2 off.
   We monitor 1.1.4 sending a 0 to 1/1/2.
   One light is on, the other off.
3) Some uses the central light switch again.
   We monitor that 1.1.1 sends a 0 to both lights.
   Both lights are off.

In the two first cases it would be easy to find out what caused the effect and to visualize it in our interface. In the last case, however, 1.1.1. would not have been the reason why 1.1.4 went off. However, from simply evaluating the last monitored events that is what we would incorrectly infer.

To be able to visualize the right state of a device we exported the configuration setup from the proprietary configuration software and recreated a data structure in our software to contain a history of the individual devices. This way, we would know that a certain device was already off and thus its state was not affected by the message sender. Another common practice to implement central control functionality, is to propagate commands by including the multiple individual group addresses in a central group address. In this case, it is also difficult to backtrace the actual cause of an effect. We simplified this for our first prototype by looking up all device-related events monitored on the bus in a specific time range to see whether there was more than one potential cause. New KNX devices increasingly contain more logic and sophisticated functions within them. For example, they can have internal schedules that block the reaction of the device, only passing on the received broadcasted message during specified hours. This makes the messages observed on the KNX monitor difficult to interpret if the configuration does not follow best practices or conventions which say that devices should broadcast their state after a message was received.

Thus, we implemented mechanisms to hold information and to compare whether a state change was reported earlier.

Both households had logs of the communication on the KNX bus in CSV files, which we parsed in order to provide them with pre-existing content in the calendar at the beginning of the study. In one case that was a week of data, in the other case, a month. We parsed those with the mechanisms we implemented for the live logging in order to visualize not only the events but also their potential causes.

Feedback Mode and Logging Mechanisms

We wanted to collect data not only from interactions with the interface that we could log, but also by allowing participants to easily provide us with feedback. To allow for a flexible and simple way to do so, we created a "feedback mode" in Casalendar. Once invoked, the main screen was surrounded by an orange frame, a screenshot of the interface was captured and users could add freehand annotation on the screen by using their finger to draw on the touchscreen (see yellow annotation in Figure 4-22) and/or record an audio file. Feedback and snapshots of the calendar entries were instantly stored on a password-protected cloud data storage, which could be directly accessed by the researchers.

4.7.3. Field-researched Case Study

Living in a smart home and directly utilizing its functionalities in everyday life differs considerably from staged usage scenarios in lab settings. To assess Casalendar's applicability to real homes, we recruited two households for an "in the wild" deployment of our prototype design for an entire month (June 2015).

Procedure and Methods

Early in our process we started recruiting participants as inhabitants of smart home that have a variety of different functions and that have already been living in them for a while are difficult to recruit. Also we wanted to learn about the specifics of those households early on to prepare for them and be able to deal better with the various unpredictable issues that tend to occur in "in the wild" deployments.

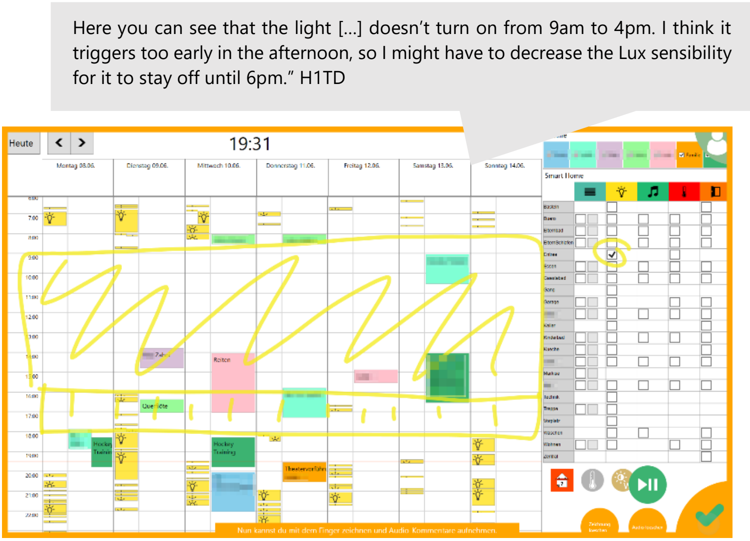

Figure 4-22: Freehand annotation (yellow) on a screenshot of the current calendar view and transcribed audio feedback

Recruiting of Participants

We recruited two households from a pool of participants from our previous study on Casalendar v2 for two reasons: firstly, we had to ask them for full access to all of their smart home data as well as their personal calendar data, thus, we wanted participants with whom we had already established a trust relationship. Secondly, we were familiar with their installations, and knew several specifics about their configurations that would allow us to more smoothly integrate our prototype into their existing systems. Both households were willing to participate without any compensation but were given CHF 300 (an equivalent of $320) as an incentive to maintain their participation over the course of the month.

Preparation for Deployment

As the integration of our prototype involved major individual customizations, we had each two meetings with one member of each household beforehand. In these meetings, we retrieved their configuration files, which were necessary to prepare our prototype for each home. We also discussed specifics of their respective installations and gave our participants the opportunity to express any concerns or questions they had regarding our deployment and evaluation. We asked for the informed consent of the parents (see Appendix E.1) and also provided them with an information sheet written specifically for the children to explain them the purpose and the procedure of our study (see Appendix E.2). However, even with careful preparation prior to the on-site installation, it took several hours to fully deploy our prototype in the actual setting.

The prototypes were placed in locations chosen by the households (see Figure 4-23). These locations were highly frequented spots which are common places to raise promote shared Public awareness (Neustaedter et al., 2009): in the kitchen in H1, in the open space for living and dining in H2. After the prototypes were running, we introduced all family members to the interface, and explained the features of our systems to them, including the feature for recording feedback. We also provided a manual (see Appendix E.6) that repeated these explanations visually.

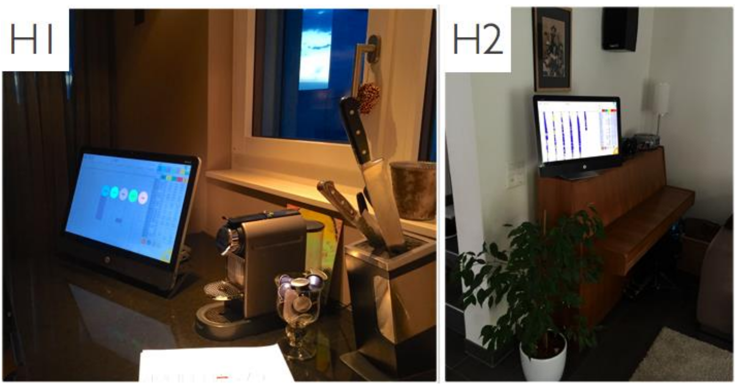

Figure 4-23: Locations in which our participants set up our prototype. Kitchen in H1 (left), living area in H2 (right)

Data Collection

We gave participants questionnaires that inquire about their opinions and attitudes towards smart home technologies before and after the study (see Appendix E.4). The questions intentionally left out any items related to our prototype in order to isolate and learn about changes in the participants' general perception of their own smart home and interactions with it. In addition to that, we also asked them to complete a questionnaire which contained items specifically targeting our interface, Casalendar. The questionnaire was an adapted UTAUT (Venkatesh, Morris, Davis, & Davis, 2003) survey, which is a standardized set of questions to assess the acceptance of technologies. The full questionnaire can be found in Appendix E.3. While our intention for this was to learn about potential usability or user experience issues that could affect other collected data, we did not use this data to make claims about the ease of use of our interface. All questionnaire items were statements and participants rated their agreement with each on a Likert scale between 1 for 'I fully disagree' to 5 for 'I fully agree'. All but two children answered the surveys.

During the study, we logged interactions with the interface and participants captured additional qualitative feedback through the 'feedback mode' of the interface. This way, we were able to review participants' screenshots and audio feedback and prepare follow-up questions for the final interview while the study was still running. These interviews, which were conducted at the participants' homes, also contained more general questions such as whether there were any unusual events during the duration of the study that might have affected the use of the calendar, whether Casalendar was a topic of family conversation and if the experiences with the interface inspired ideas about what they would have liked to change in it. Our interview outline can be found in Appendix E.5. We further sent three reminder emails to participants over the course of the study to maintain their participation and prompt feedback.

Participating Households and Procedure

For our case studies, we purposely recruited two households with different characteristics, apart from similar age and family composition, to gain broader insights about our concepts. The first household (H1) consisted of two parents in their early 40s and their three children between 8 and 14 years old. The second household (H2) also consisted of two parents in their early 40s and two teenagers, ages 14 and 15. In both cases, the fathers were working full-time and the mothers part-time.

H1 built their house with integrated smart home technology and moved in approximately two years ago, while H2 installed their smart home functionalities during a major renovation almost eight years ago. While in H1 both parents used digital calendars extensively and maintained digital calendars for their children, in H2 only the father used a personal digital calendar and maintained a minimal shared calendar to which other family members were subscribed. The mother maintained a traditional paper calendar for the entire family which was placed at a central location that could be easily accessed by everyone in the family. We recruited participants with different calendaring habits and in different phases of their smart home development to learn about potential differences in the usefulness of the calendar metaphor. As the smart home community from which we were able to recruit our participants is local and small, we have opted not to associate participants with their specific occupations to protect their privacy. In both households the setup was typical to the households we found in our empirical work, in which the husband had extensive technical knowledge and was heavily involved in the configuration of their own home and could be considered an early adopter of such technologies.

Analysis

First, we evaluated the UTAUT survey to learn whether issues with the usability or acceptance of the system could have severely influenced the usage of the system. Then we looked at differences between the pre- and post-deployment surveys that asked about participants' opinions and attitudes regarding smart home technologies. As the data sample was too small to allow for statistically significant results, we instead focused on looking at noticeable differences among individuals, between households, or user types. We classified changes as noticeable if the answer before the study differed by at least two points from the answer given after the study, or if multiple participants' answers changed in the same way. As those changes might have occurred by chance, we checked for consistency with the qualitative feedback from interviews and feedback given through Casalendar, which was partially transcribed and analyzed using open coding. We only considered results and insights from our quantitative analysis that were consistent with the qualitative feedback.

4.7.4. Findings

In the following section, we present what we learned about the appropriateness of the calendar metaphor in the smart home context, emerging usage patterns with our interface, and social implications we observed. We will refer to the participants by using the household number and PU for describing the Passive User, TD for the technology driver, and K# for their children.

Appropriateness of the Calendar Metaphor

The usage we observed and feedback we collected revealed several benefits and limitations regarding the suitability and appropriateness of a calendar metaphor for smart home user interfaces, which was our main interest in this study.

Beneficial for Providing an Overview of Behavioral Patterns

Participants reported that the weekly overview that incorporated multiple functions and sensors was good for giving them an overview of behavioral patterns of the home and the family. H1PU described this as *"You quickly have an overview [of] what my family is up to"* and *"[I can] see the whole week, how the home has behaved."* As mentioned earlier, many commercially available smart home interfaces displayed the various functions in individual, isolated visualizations. While this allows one to choose the best-fitting representation of the data, it makes it more difficult to draw insights about the overall behavior of the home.

We found that visualizing the data on a timeline provided an easy way to spot issues in the configuration, due to the natural association of cause and effect. In some cases, it also facilitated the definition of actionable changes to the existing configuration. For example, H1PU noticed that the shades were not acting as she wanted them to in the afternoon and early evening (see Figure 4-24 left). By visual inspection of the calendar, her husband was able to identify unexpected brightness changes as one potential cause (see Figure 4-24 right). This is an example of the calendar offering a means to facilitate communication between family members to solve suboptimal configurations of a smart home.

Visualization in a calendar provided a good overview and easy spotting of exceptions.

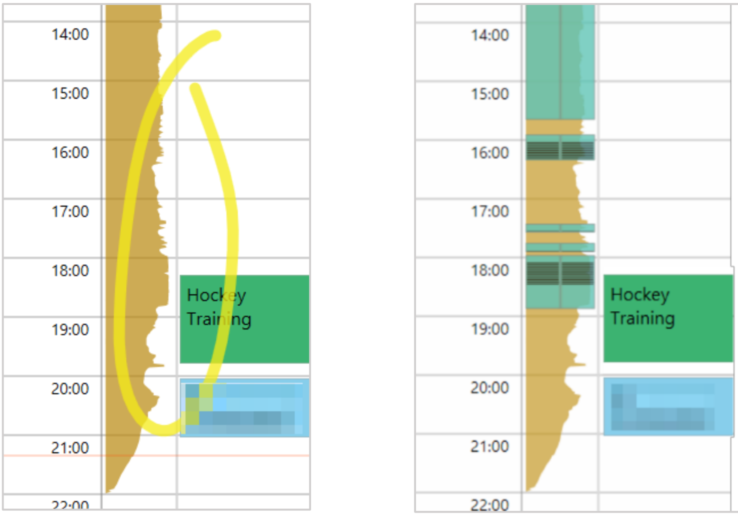

Figure 4-24: (Left) user annotation of an unusual peak in the brightness sensor data; (right) between 5 and 7 pm: the unwanted behavior of the shades observed by the wife

Establish Trust in the Home Through Temporal Anchors

Participants' responses to several questionnaire items about trust and understanding were slightly increased after they had used Casalendar for a month. For example, their average agreement on "If something happens automatically in the home, I know why it happened" increased consistently by 0.5 points for all participants. H2TD, who was previously wondering about a specific function in his home further reported: *"It's visually obvious to me now that there are no malfunctions. Till now, I've assumed that the light in the basement is periodically turned on without any reason."* One potential explanation could be that the familiarity of the calendar metaphor, with calendar entries being associated with events taking place, increased feelings of trust, which was described by participants of our lab studies on Casalendar v2. However, even in a personal calendar it can be uncertain whether personal entries actually took place (Tullio & Mynatt, 2007). We assume that participants may think of the home's events as a defined schedule rather than a dynamically adapting calendar. This understanding may be challenged by a future version of Casalendar which could include future event predictions that are automatically inserted by the home and continually adjusted over time.

Visualization as calendar entry increased trust in configuration.

Usage Patterns Around Smart Home Events

Two primary use cases emerged in our deployment: checking on the home's behavior retrospectively and verifying the configuration.

Retrospective check

Our participants reported enjoying having a familiar tool to turn to when they want to check on what was happening at home while they were absent. This type of behavior was one of the use cases that was frequently mentioned by participants in our previous studies as being challenging and thus what we designed for. The retrospective check included information on the family and the home's functions. For example, H1PU wanted to know what her children had been up to, while H2PU wanted to learn about the Roomba's activities.

Checking on events that happened while having been absent.

The information they retrieved from Casalendar also became a conversation topic and a tool for reflecting on the patterns, not only for the adults but also for the children, as expressed by H1K2: *"We just saw* *for how long the light was on, or whether we forgot to turn it off, or whether we forgot and left the music playing."*

Configuration Verification

Participants appreciated having visual feedback that allowed them to confirm that the home had worked as expected. For example, H2TD wondered whether the motion-triggered lights in the basement were working properly, and H1PU wanted to verify whether the configuration changes that her husband carried out actually worked.

Checking on specific events to verify configuration.

While both of these usage patterns seem similar, the intentions were slightly different: In case of the retrospective check, the inhabitants' focus was on learning about details of the automation technology's behavior or other household members' behaviors without a specific expectation. In case of the configuration verification, they focused on whether or not something worked as expected, and compared their expectation with what was visualized.

In our informing interviews for Casalendar v2 participants stated to rarely look at past events in their calendars and we interpreted this to be a challenge for a seamless integration into the common calendar usage routines of people. In our field study people did not comment negatively on this potential disconnect from their natural use of a calendar. However, this will need to be studied further by conducting longer term studies with a prototype that addresses more of the general calendar guidelines as discussed earlier in Section 4.4 (Designing Casalendar) as well as by logging their involvement with the prototype and the emerging patterns or use cases after the novelty effect of it wears of.

Although our sample size is limited, participants' feedback indicated that the duration of habitation in a home affected the benefits an interface can provide. We hypothesized before the study that H1, who had been living in their home for less than two years and still found itself in the phase of iterations (Section 3.3.3 – Iterating until it fits), would consider Casalendar more useful than H2 who had been living in their home for more than eight years and who reached a phase of stability (Section 3.3.3 – Reaching (temporary) stability) as they had already fixed many issues of its behavior through many iterations. This was confirmed by their responses in our questionnaire: H1's perception of whether Casalendar increased the chance to set the home in the way they wanted it to be was higher than H2 (H1 M=3, H2 M=1.5). Similarly, H1 agreed that Casalendar could help identify and understand problems quickly (M=4), while H2 thought less so (M=2). H2 reflected on the usefulness of our interface in the early stages of the smart home adoption. H2TD (husband): *"I had to change so many things over and over again, and then it still wasn't like the way you had thought. The temporal sequence [of actions] took a lot of adjustments [to get it right]."* H2PU (wife): *"You could have simply looked at the whole week [in Casalendar] to see how the home has behaved."* They considered the calendar-based interface to be useful to see patterns and exceptions in the weekly overview at a glance. H2PU was generally happy with the interface she currently uses after making several adjustments and she reported having gotten used to interacting with these tools. However, she noted that she would have adopted Casalendar, if she had been given this option earlier, since *"[with Casalendar] you simply have it all [, the different devices and calendar] in one [interface]."*

Tool to visualize a configuration's effects and patterns could help to improve early iteration phases.

Usage Patterns Around the Integrated Calendar

When designing the interface, we considered scenarios in which the context of the personal calendar could potentially be connected to the smart home's behavior (for example by having the robot vacuum clean the house before a visit that is entered as a personal event, or deactivating the shades to the garden when guests come over for dinner in order to not disturb them). Yet, neither in the collected annotated screenshots nor in the follow-up interviews did examples like this, or any other specific interest in connecting personal calendar entries with smart home behavior, come up. However, participants mentioned the usefulness of seeing their calendar entries collocated with the behavior of the home. E.g., H1PU commented on that they would have liked to define exceptions for the shades when seeing that a school holiday was coming up. But despite hoping to find strong evidence for this to be a promising approach, the actual usefulness of such a functionality is still unclear. This idea might be worthwhile to reevaluate when our prototype a) has more control over various devices and b) when calendar entries have more automatically retrieved information on the context such as locations of events or commute times.

Having personal and home events in one interface was mostly of interest to allow informed changes rather than to connect individual events with the home's behavior.

In general, our participants felt that they had lost interest in the smart home's actions after living there for a while. They believed that the true purpose of a smart home should simply be to *"function optimally in any situation and the user wouldn't need to worry about questions like 'will the shades go up and when will they go down?'"* (H1PU). H2 had substantially less interaction with the interface than H1. We attribute that to the fact that there is generally little need and interest in the smart home data most of the time. This makes sense: smart-home inhabitants want to enjoy peace of mind (Bernheim Brush, Lee, Mahajan, Agarwal, Saroiu, et al., 2011b) and worry about fewer things, not more. H1PU expressed interest in using one single interface for both smart homes functions and the family's calendar and said: *"I would like to also be able to edit the [personal] calendar entries [in Casalendar], so that I could get rid of the iPad entirely."* The same household also reported how they were using *Casalendar* exclusively to look at their own calendars when they had a very busy week during our study. Therefore, we propose to integrate informative data about the smart home's behavior into an interface that is frequently used in the user's everyday life. The integration should be carried out in a way that only draws the user's attention when it is needed and otherwise stays in the background or can be easily ignored.

Integration in already-used tools could help directing awareness to data that is of low long-term interest by itself.

H1 used their digital calendars extensively and we observed a more natural integration of their interaction with Casalendar into the daily habits of the family compared to H2. We argue that the acceptance of such an interface will be highest, if a) users already habitually use digital calendars and b) are not in a saturated phase of their smart home configuration.

Tradeoff Between Completeness and Visual Clutter

The challenges of designing usable interfaces which incorporate dense information is certainly not new. One of the many guidelines for good design states that "the display should be designed to convey 'just enough' information" (J. Mankoff et al., 2003). Although we tried to address this issue with user-specific information and view filters beforehand, we observed a frequent tension between an interest in accessing more information and viewing less data in our participants' feedback. Our participants reported sometimes being overwhelmed by the amount of information presented. H1TD recorded the screenshot

Interest in visualizing more data challenges a simple and glanceable visualization.

shown in Figure 4-26 and his comment: *"[…] I simply selected all shades […] and now there's a bunch of individual bars and that's all very confusing."* At the same time, they also expressed the wish to include more data in the interface. H1TD and H2TD would have liked to see numerical values next to the temperature and brightness graphs on the timeline. Ideally, the interface would manage high information density and create a view that is useful and actionable for the user.

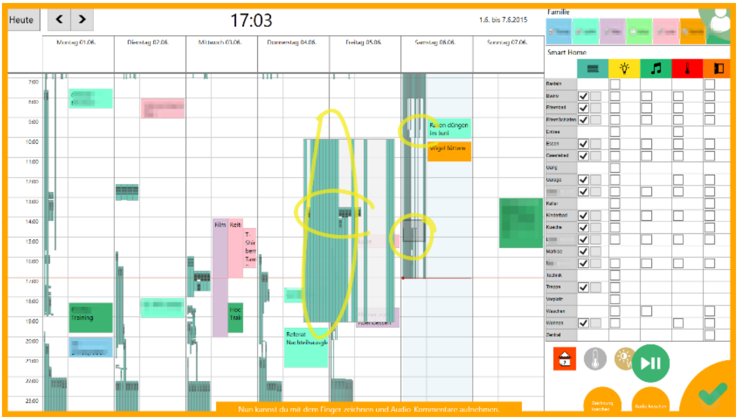

Figure 4-25: H1TD annotated and commented on visual clutter when visualizing all shades

More Reflection and Context Needed Over Time

Over time mere representation of events was not sufficient and further actionable insights would be needed.

We observed that our interface was only interesting for a short period for the participants who had been living in their smart home for a longer time and were already familiar with their home's behavior. H2TD commented: *"In the beginning [Casalendar] was very interesting, however, over time it wasn't […] interesting to look at it over and over again because in the end it doesn't really change a lot."* He felt that his trust in the home's behavior was confirmed after a while and he *"doesn't check all the time whether it still runs correctly as [when he checked it] last time."* He stated that he would instead be interested in learning about certain trends in the home's behavior and recent changes to the configuration. Strengers (Strengers, 2011) made a similar observation of saturation on inhabitants who have been provided with eco-feedback for some time. This seems to be very common also for events of people as studies showed that people using paper calendars do not write down their routine events after a while (Neustaedter et al., 2009) which was also confirmed in our informing interviews described in Section 4.6.4 (Personal Calendar Usage). An interface that leverages the calendar metaphor thus could potentially benefit from fading out or simplifying certain patterns and only point to exceptions thereof.

Presenting information that is relevant to the user at a specific moment is very essential. Related work looked at various techniques on how to prepare information to people in such context-aware environments, so as to make it useful to users (Vermeulen et al., 2010). This does not only concern events that happened, but also events that did not, because people will also still wonder why expected events did not take place (Lim & Dey, 2011b). For example, H2PU stated a strong interest in these questions and other unusual behavior. She wanted answers to questions such as *"did the iRobot really run, or was there a black out?"*

Other participants stated that they would not only want to see entries that would allow them to understand the home better, but also support them in spotting exceptions in the sensor data or home's behavior. H2TD described it as: *"[It would be helpful] if you could see […] 'was that only an exception?' or is that the typical course of actions. At the moment, I always have to figure out, was it an exception or my mistake [in the configuration]?"*

Lower Barrier of Access for Smart Home Interactions

In our empirical work in Chapter 3 we found that many common smart home technologies require people to have technical skills to gain access to all information and/or control functionalities. We were therefore interested in how our approach would be perceived by the different types of users.

Access for the Entire Household

Our interface was well received also by the technical drivers who had access to the log files and other visualizations from the beginning. Our prototype was simpler to access for them too, and the calendar visualization was easier to parse, as reported by H2TD: *"Well, I could go into the logs and see that there, but here in Casalendar it's visualized very* *comfortably."* A shared visualization that is usable by all family members, regardless of their technical skills, could help to support communication of problems and ideas for the configuration, and thus improve the initial configuration phase.

Accessibility of the metaphor, as well as of the device, lowered the barrier to using our prototype for all family members.

Our interface design was based on the metaphor of shared, physical calendars that can be accessed by everyone at any time, as opposed to tools on personal devices that are often access-restricted. In the participating households, some family members had limited access to the devices on which the control interfaces resided. For example, in case of H1 the data on sensor data (temperature, brightness) was only accessible through interfaces that were never introduced (or of any real interest) to most household members, and only installed on devices that had restricted access, as described by H1K2: *"On mama's [iPad] we can't do that because [the iPad] is locked."* Our prototype *Casalendar* was not access-restricted, which was well received, as described by H1PU: *"The kids enjoy using the calendar view, but they also play around with the smart home functions in there because the iPad is locked."*

We discussed previously how children can be a security threat to a smart home (Section 3.3.4), thus it is natural that parents would not want to give them the same access as they have themselves. In our prototype there were only very limited functions to control smart home functions and no options to consciously or inadvertently change the configuration of the home. The participants' feedback makes us confident that our interface took a step in the right direction toward achieving our primary goal: create an interface that was perceived accessible by the multiple participants in the home. If more features for control and configuration changes will now be added to the interface it has to be taken into account that this might influence the Passive Users' confidence and comfort in interaction with it.

Emerging Questions of Privacy

Contrary to our expectations, our participants reported no privacy concerns about *Casalendar* revealing information to other household members and only TDs agreed or strongly agreed that they would not want information to be shared outside of their household (M=4.50). PUs disagreed or strongly disagreed to this statement and thus, did not share this concern (M=1.50). Privacy concerns did not come up in the interviews either, although we specifically probed for them. Only H1PU commented that her children could potentially have concerns in the future: *"We could associate the fingerprints to the kids sometime in the future. We could check which kid got home at what time after they have been going out at night. Hm, they will probably not be overly happy about that."*

While data collected from individual devices (for motion-triggered lights in the basement or electricity measurements of the kitchen stove) might not instantly raise privacy concerns for the inhabitants, they could easily be turned into a sophisticated surveillance system just by being put in the context of the entire home (Ur, Jung, & Schechter, 2014). This is not unique to calendar representations, however, the increased accessibility and the promoted awareness, make careful design to maintain privacy especially important. From the patterns in the timeline, H1PU was able to infer when the children came home and whether they actually heated up their lunch or whether they went straight to the basement to play computer games. We found that our visual representation of data helped users to easily capture exceptions or outliers of certain patterns or events at unusual times. For example, H1PU noticed an unusual entry located in the basement one night, which she recorded via an annotated screenshot in our feedback mode (see Figure 4-26). After casually talking to her husband about it, he admitted having fallen asleep after watching TV for too long and then checking up on the cats before going to bed. In this case, both household members felt comfortable sharing; in other cases, a simple smart-home calendar entry might violate a person's privacy or cause arguments.

Accessibility of metaphor makes existing privacy issues more evident.

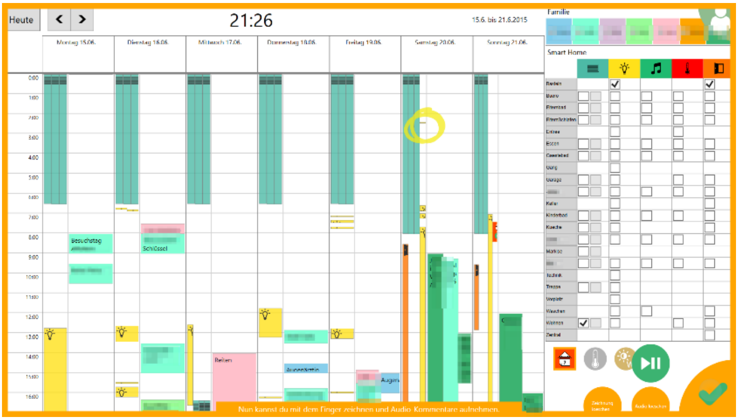

Figure 4-26: H1PU's annotated an unusual entry in the basement via the feedback mode of Casalendar

4.7.5. Discussion and Implications

In this section, we discuss our findings and provide several implications that aim to support the design of future systems. Moreover, our discussion aims to raise emerging questions that take into account the limitations of our interface prototype and our case study.

Calendar or Smart Home Interface

People's existing usage of tools shapes how a hybrid interface will be used.

We designed our interface to primarily look like a regular calendar interface, as reflected in our decision to give personal calendar events more space than smart home events in our interface. However, we noticed that the perception of whether our hybrid interface was primarily a calendar or a calendar-style smart home interface could vary based on the usage and configuration, and the extent to which digital calendars are already in use in a household. As a consequence, the question arises whether it makes sense to present Casalendar primarily as a smart home interface in the form of a calendar or to present it as a subtle integration into something that is primarily a calendar interface. Both would share similar properties, such as presenting smart home events on a timeline and providing an overview across devices and days that makes it easy to spot patterns, exceptions, and causalities. From our study, we learned that the smart-home data and logs themselves are not interesting enough to justify a stand-alone interface most of the time. Additionally, work by Palen (Palen, 1999) revealed that simply replacing the calendar artifacts that people use can create major challenges with regard to their routines. Thus, we believe that integrating smart-home data into frequently used tools will be the more promising approach compared to only focusing on visualizing the data – as long as it does not compromise existing practices with these tools or require extra effort from the user.

A calendar interface is without a doubt more familiar and accessible to the wider population than technical smart home interfaces or log files. In our study, we found that no one had trouble understanding our interface concept, which helped the households to build trust in the technology. However, we also reached the understanding that one interface cannot serve all purposes equally well. Although we offered limited options to control features of the home, as this was not the primary focus of our study, it gave us some early insights about participants' opinions of the metaphor of a central calendar for control purposes. H1PU raised concerns regarding the limited practicality for simple controls, such as letting the shades down. She expressed that she does not want *"to have walk up to the calendar for this simple action."* This would be a problem for any interface that is not mobile and has to be accessed from a specific location. While this might be addressed by making Casalendar accessible from mobile devices on phones or tablet PCs, it also hints at that immediate control of devices is not well supported by this metaphor. Still, participants expressed that they want to be able to access specific control functions when they see events of this function in the interface. Hence, such a visualization interface should include the means to control the devices presented or their configuration even if it will probably remain only a complimentary tool to other means of control. When integrating means for control of multiple devices into a single interface, the design challenges that are known from previous approaches to "universal remotes" (Nichols et al., 2002), such as preventing mode errors, will have to be taken into account.

While an integration of control functions will be required, they will not substitute other means of control.

To address the diversity of tasks, multiple metaphors should be used in combination.

Our interface helped our participants get a better idea of the temporal behavior of their home, and they could create focused views on it using the different filter functionalities. Yet, for use cases in which only the current state is of interest, a spatial metaphor might serve better. For example, when leaving the home and trying to find out which windows are still open, a spatial interface such as a map would only require one view. In our interface, the user would first have to orient herself within the timeline and then see whether there were events related to all the devices of interest. As mentioned earlier, we believe that the visualization of smart-home data we propose here will probably not suffice as a stand-alone application. Integration with another interface might offer other advantages as well. For example, by integrating temporal and spatial interfaces the use of a selected location could customize the calendar view and reduce visual clutter. Offering multiple metaphors could also allow for a more versatile use of the system.

Integration into used tools could facilitate re-learning issues of infrequent use.

As we learned in our empirical work, in the phase of (temporal) stability (see 3.3.3) there are only few changes to the home that might result in behavior which participants take an active interest in. Thus, an interface whose sole purpose is interactions with the smart home will probably be used less frequently as well. In our early study focusing on Passive Users (see Section 3.4.3– Passive Users are not "passive" per se"), we found that one reason why people are Passive Users is that their infrequent use of the technologies makes the interactions more cumbersome. While they might have learned how to use an interface at some point, they simply forget how to use it over time as they do not use it regularly. An interface style that is frequently used in one's other aspects of life may help one to quickly familiarize again with the smart home interface when it becomes necessary, and may help achieving incidental intelligibility (Yang & Newman, 2013) to more easily understand underlying problems. We believe that an easy, low-barrier transition to the smart home interface would encourage people to adjust and update the configuration. While this does not necessarily enable people to fix all problems they might have with their home by themselves, it might be a first step to address the issue that inhabitants often put up with a sub-optimal configuration as identified in Section 3.5.4 (The Tension Between Comfort and Control).

Calendar as a Sensor and Tool to Facilitate Future Controls

Despite the small sample size, our deployment of Casalendar in real households confirmed our initial assumption that a familiar representation of information that is usually captured but hidden in log files can be useful for inhabitants. But capturing this information could also serve another purpose: in addition to offering automated behavior that remains rather static and inflexible after the initial setup (Stringer et al., 2006), the house could use it to play a more active role in the household. By aggregating information about the context of everyone's whereabouts through the calendar, the home could better understand the dynamics of the household and adjust to them. Prior work by Davidoff (Davidoff, Lee, Dey, & Zimmerman, 2007) demonstrated how such information on people's routines can be used to create more valuable ubiquitous computing systems. Other work used calendars as sensors to collect information, in order to automatically annotate images with context information (Gallagher, Neustaedter, Cao, Luo, & Chen, 2008). People already use calendars for tracking past actions (Palen, 1999), and annotations on the calendar have been used to support awareness within the family (Neustaedter & Bernheim Brush, 2006). A smart home could potentially do the same thing: it could use the information about interactions with the building infrastructure to allow a better adaptation to the family or to create a means for the inhabitants to more easily set their home to a specific state. For example, the home could look back at personal events (such as "Spring break", "Dinner party", etc.) and try to correlate them with the changes to its configuration to learn about how it could interpret them. Then, it could offer "autocomplete"-style suggestions/predictions when adding or changing a device/configuration or when adding a new personal calendar event. This could permit a more optimized use of the technologies and reduction of manual overrides, assuming that the reconfiguration was too demanding for the user previously.

Aggregation of information that is collected in calendars could provide the home with context to better support its inhabitants.

We only showed manually generated future information about the potential behavior of the shades. Therefore, we could not gain many insights about how people would interact with predicted events from our study. Yet, participants expressed interest in having the various scheduled events of different devices or functions included in the calendar interface. For example, H1PU considered it helpful if she could see the starting time of her stove on her calendar when she programmed it in the morning. That way she could react to potential conflicts occurring in the course of the day by adjusting the preprogrammed time or canceling it. H2PU wanted to include the weekly vacuum-cleaning schedule of the robot in the calendar for the same reasons. She also wanted to include contextual information that was potentially relevant to the home like the weather forecast, so that she could easily change the home's settings accordingly. Merging all this data into one interface could help create a mutual understanding of what the home bases its actions on. Yet, when introducing uncertain and potentially changing data, a challenge that is already known for shared calendars will have to be considered: how does the inhabitant stay ahead of changes that occur throughout the day (Neustaedter & Bernheim Brush, 2006)?

Questions remain open as to how dynamic schedules of the home will be perceived.

Transparency vs. Privacy

Our interface has shown the potential to provide more transparency, to act as a base for communication and to allow the less technical household members to understand and refer more easily to certain behaviors of the automation technology. In the case of H1, we also observed how the home acts as an extended monitoring system that provides a more tangible way for parents to address some behavior patterns of their children.

Our interface raised an additional question regarding privacy, besides the general questions of collecting such data: what does it imply if smart home data is offered in an accessible tool that makes it very visual, and thus easily consumable for all household members? Should the entirety of the data collected be available to all household members? Even regular calendar entries can make users vulnerable to external judgment (Palen, 1999). What will happen when a teenager misses curfew by a couple of minutes, leaving a distinct visual pattern on the calendar? Will a tolerated "white lie" become intolerable because of the calendar entry it creates? This scenario has been studied by Ur et al. (Ur et al., 2014), revealing attitudes of parents and teenagers. One of their design recommendations is to make the logs less granular, such as showing "around 11pm" instead of the exact timestamp. A calendar interface

Inhabitants' behavior visualized as discrete events could affect how people treated them before.

visualizing such logs would therefore need to be able to have a suitable representation for such fuzzy entries.

Privacy issues or challenges in smart homes are not new; the data in such homes has always been available but accessible only by one or few members of the household and buried in a list of log entries. In some ways, this has created an imbalance in access to information about other family members. If interfaces, like Casalendar, suddenly make previously obscure data usable and democratize access, new privacy issues and questions regarding the rights to access smart home data will be exposed. Who should know about what in a household? Who should be able to filter this information? Behavioral patterns can be spotted easily in the calendar interface, as they have a specific visual appearance. There are several approaches in privacy research, such as adapting information to context in ambient calendar displays (Schaub, Lang, Könings, & Weber, 2013) that could be considered, even for interfaces situated in a more private context. Most importantly, these questions need to be recognized as major challenges that will require sensible design choices, in order to avoid negative social implications on family dynamics.

4.8. Summary

In this chapter we explored how people's experiences of smart homes could be improved by including the notion of a home having and communicating its own routines and behaviors. Inspired by people's use of calendars to manage their schedules, we created Casalendar, a calendar for the home that integrates its inhabitants' calendars as well.

We learned that the integration of the home into tools that are already used in inhabitants' daily practices can encourage its use and help people to check on what the home did in their absence, or whether it acted in the way they programmed it. However, this integration needs to maintain the standards of the tool that it is being integrated into. For example, the restrictions of our prototype for the functionality as a personal calendar, while accepted for the duration of the study, would inhibit the use of our system in a more long-term scenario. Still, the users' general familiarity with calendars helped in addressing our goal derived from Chapter 3 particularly for Passive Users, i.e. those with a less technical background. This metaphor helped to lower the barrier for access and showed potential to increase awareness across the whole family. While this did not create new privacy issues as there was no additional data being collected, the more easily accessible visualization emphasized the need for careful design in future systems. The interest and need for the home to provide more reflections and actionable insights as opposed to merely collecting and visualizing data, which our participants expressed, point to the progression from homes that are merely automated to homes that are proactively supporting. In order for the smart home to be valued over longer durations of time, people expect it to provide "smarter" information, to reflect on their behavior and support the inhabitants to achieve their unique sets of goals.

Chapter 5. Personality: Learn About Agency[5]

While Casalendar offers an approach to address issues of current smart home user experiences, we also wanted to conduct a broader exploration probing into different future experiences with homes that might act more proactively, in order to address the challenges of overwhelming the user with all the options for control and configuration that are available, as presented in Chapter 2. To learn about the notion of agency and people's attitudes toward this concept, we created a lab prototype (see Figure 5-1) designed to express two different personality composites, with the goal of using human-like personality traits to set expectations of the home's behavior.

Figure 5-1: Participants experienced a home's potential behavior for two personality variants along several steps of the same usage scenario: (1) she wakes up and is presented with relevant information, (2) the home detects her mood in the bathroom, (3) it sends a robot as the inhabitant wants to leave the home, (4) it presents her with information as she comes back, (5) it interacts with her as she turns on the TV, and (6) as she goes to bed.

In this chapter, we describe how we chose the personalities we designed our prototype to express, how our study was conducted to learn about our participants' attitudes towards our design and we discuss the implications of our findings.

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5 Based on: **Mennicken, S.**, Zihler, O., Juldaschewa, F., Molnar, V., Aggeler, D., & Huang, E.M. (2016). "It's like living with a friendly stranger": Perceptions of Personality Traits in a Smart Home. To appear in *Proceedings of the ACM Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '16)*.

5.1. Motivation and Approach

Heterogeneous devices lead to a multiplicity of interfaces inhabitants have to interact with.

We found, as did Brush et al. (Bernheim Brush, Lee, Mahajan, Agarwal, Saroiu, et al., 2011b) and as we discussed in Part 1, smart home research faces the increasing challenge of creating easily graspable, seamless interactions for inhabitants while handling a rising number and heterogeneity of devices, services, and technologies. The technical challenges of unifying such systems in smart homes have long been recognized by the research community (W. K. Edwards & Grinter, 2001). A common approach to deal with the complexity of multiple devices and fragmented control of connected devices is to create an integrated interface that unifies these various technologies. Doing so gives the inhabitants the impression of interacting with the home as a single entity, rather than feeling as though they are engaging with multiple systems and interfaces. Agent interfaces like Apple's Siri (*Apple | iOS Siri*, 2015), Amazon's Alexa (*Amazon | Alexa Developer Portal*, 2015), or Microsoft's Cortana (*Microsoft | Cortana*, 2015) are another approach to abstracting complexity and they afford the discovery of functions through conversations. These technologies provide a unified interface which allows users to access heterogeneous functionalities with spoken natural language, instead of having to navigate complex, deep menu structures. Of course, interface agents come with their own limitations, such as a lack of direct manipulation (Shneiderman, 1997).

Speech interaction can offer an abstraction layer.

Due to the increasing adoption of machine-learning functionalities in smart home solutions, as we found in our review of literature and industry products in Chapter 2, interface agents will not only need to handle diverse technologies, but also the automated behaviors they will perform based on the recognition of inhabitants' activities. Given the increasing ability of homes to behave proactively, in the future we might not only live in, but also with our homes as they take a more active role in home interactions and routines. Commercial interfaces like Siri and Alexa are starting to integrate access to connected home functionalities. People can now "talk" to their homes in a conversational style, though the interaction is not necessarily natural or smooth as of yet. As interactions progressively allow people to use natural language, they will also increasingly resemble human conversations or dialogues.

Previous research has found that certain aspects of human social interactions carry over to interactions with technologies (Moon, 1996; Reeves & Nass, 1998). If a home starts engaging in conversations through an agent which is designed to mimic specific human traits, it will certainly not be an exception from this transfer of human interactions. Knowing from related work that personalities influence how people interact with each other (Höök, 2004) and that people associate personalities with technologies (Reeves & Nass, 1998; Sung, Guo, Grinter, & Christensen, 2007), we wondered what this might imply for people's expectations of the home. Do inhabitants want an interface that exhibits a personality? Would it be beneficial for the user experience? If so, what kind of personality traits should it show? Should a smart home be proactive or passive in providing functionality and intelligence? What roles should it take on? Should it act as an assistant? A friend? A caretaker? We have built on these ideas and created a prototype that made personality the primary focus of our investigation by designing and contrasting two home personalities as prototype systems based on the Big Five Model of personality from psychology literature (Digman, 1990; Goldberg, 1990). We evaluated how people respond to the personalities manifested in the prototypes and further used the design to probe the larger question of smart home personalities.

Certain aspects of human interactions, including perception of personality, carry over to interactions with machines.

5.2. Related Work and Inspirations for Design

In this section, we introduce different categories of agent interfaces, our understanding of personality and the attributes associated with it, followed by how we leveraged prior work to design personality traits in smart home technologies.

5.2.1. Agent-based Interfaces

As systems increasingly take advantage of machine learning and AI advances, they exhibit more active or proactive behavior. In our work, we look at how agency can be applied to smart home interfaces to provide users with a consistent, self-explanatory interface when dealing with multiple different devices and services.

Often, agent interfaces include a visual, embodied representation of their system such as an avatar (Höök, 2004). Previous work has looked at different design aspects in an isolated fashion, such as the influence of the visual design of agent-based systems on user satisfaction and perceived quality (Kühnel, Weiss, Wechsung, Fagel, & Möller, 2008). Often work in this space focuses on assessing a system's success or acceptance for a specific task, such as language learning (Kanda, Hirano, Eaton, & Ishiguro, 2004) or driving (Jeon, Walker, & Gable, 2015). In our work we aim to apply agent interfaces to everyday scenarios in smart homes. An example of a previous agent-based interface that was also designed for smart homes is Genio (Gárate, Herrasti, & López, 2005). Its goal was to offer a virtual butler that responds to the user's voice and generates multimodal output including speech, graphics and actuation of appliances. As it was found that the visual design of an avatar has a much stronger impact on participants' expectations for the capabilities of the system than speech output (Kühnel et al., 2008), we decided not to provide a visual avatar to reduce the obtrusiveness of the agent.

5.2.2. Embodying Personality in Machines

Agent interfaces are increasingly used in consumer technologies, such as Apple's Siri, Amazon's Alexa, or Microsoft's Cortana. These systems all incorporate some human-like qualities including social behaviors and personality traits in their responses. Cortana, for example, tailors responses and jokes to different geographic locations (*Windows Blog | Cortana,* 2015) being, for example, more formal in some Asian countries. There has also been research done on humor, an important aspect of human interaction, looking at whether computers can understand and generate their own humorous content (Shahaf, Horvitz, & Mankoff, 2015). Other aspects of human interaction could be integrated into interactions with computers. For example, studies have found that people's responses to flattery and praise are similar, regardless of whether it comes from a machine or a human (Johnson, Gardner, & Wiles, 2004; E. J. Lee, Nass, & Brave, 2000). Gockley et al. (Gockley, Forlizzi, & Simmons, 2006), who studied people's reactions to a personality exhibiting robot in a public setting, found that differently designed personalities affect the amount, frequency, and duration of interactions. While not explicitly focusing on the expression of personality, Lee et al. (M. K. Lee et al., 2008) explored various levels of proactivity demonstrated by smart homes to gain insights about what roles it could play in dual-income families' lives.

People are able to attribute personality traits to text-to-speech output (Nass & Lee, 2000) and different voices. An example is in navigation systems in which these associations can affect trust in systems (Large & Burnett, 2014). The fact that people's emotional response to perceived human-like aspects of machines is similar to their emotional responses in human-human interactions underlines the importance of careful design for systems that exhibit human-like personality traits.

5.2.3. Definition and Aspects of Personality

Personality can be defined as "a system of parts that is organized, develops, and is expressed in a person's actions" (Mayer, 2007). We applied this notion by conveying personality traits as output through a variety of devices and media. The personality variants of our smart home scenario were designed based on a commonly used model for describing personalities, the Big Five or Five Factor Model (Digman, 1990; Goldberg, 1990). In this model, a personality trait can rank either High or Low on one of five independent dimensions of personality: Openness, Conscientiousness, Extraversion, Agreeableness, and Neuroticism (McCrae & Costa, 1987). Instead of using the abstract descriptions in our questionnaires, we used descriptive adjectives that have been found to map these dimensions, such as "Organized" or "Thorough" instead of "high Conscientiousness" (see Table 5-1).

We created two agent experiences exhibiting different personality traits for the same usage scenario. Rather than trying to design universally recognizable representations for the chosen personality traits, we intended to create noticeable differences between the designs. This was done to give participants an idea of the experience living in these homes and also experience what characteristics they would or would not appreciate in the home.

Table 5-1: Mapping from attributes to personality dimensions (from (Motzek, Kos, & Gupta, 2011))

Personality trait	**Representative attributes**	
	High	**Low**
Neuroticism	Emotional, insecure, moody, anxious, depressed, angry, embarrassed, worried	Self-confident, secure, assured, hopeful, encouraging
Extraversion	Talkative, assertive, energetic, social gregarious, active, lively	Introverted, reserved, withdrawn, silent, inactive, unsocial
Openness to Experience	Curious, imaginative creative, original artistic, broad-minded	Stubborn, unimaginative, uncreative, narrow-minded, unoriginal
Agreeableness	Cooperative, forgiving, modest, tolerant, trustworthy, courteous, flexible, soft hearted, altruistic, sensitive	Aggressive, argumentative, suspicious, confrontational, impolite, inflexible, egoistic, insensitive
Conscientiousness	Organized, persistent, thorough, responsible, goal-directed, careful	Disorganized, negligent, undisciplined, irresponsible, unsystematic, careless

5.3. Designing Personality Traits in an Automated Home

When designing functionalities inspired by personality traits for smart home behavior, our goal was not to design the functionalities such that the underlying personality trait could be universally and consistently recognized. Instead, our goal was to create varied experiences of agents based on personalities that would allow participants to experience different points in the design space. Each experience should then provoke different responses such that our participants could reflect on what living with such a home could be like. The experiences were also intended to help them expressing what they consider to be desirable or unwanted traits.

To provide our participants with two very different experiences, we chose two combinations of personality traits ranking high or low on different dimensions of the Big Five model: we combined high Conscientiousness and Agreeableness into our Conscientious, Kind, and Calm design (CKC) and high Extroversion and Openness into our Extroverted and Cheerful design (EC). We decided to not consider Neuroticism for our designs as it is mostly associated with negative attributes such as Moody, Insecure, or Depressed (Motzek et al., 2011) and our other explorations in affective computing which we will present in the next chapter also suggest that people dislike negative feelings about inanimate objects in their home.

Of course, there is no natural mapping for specific observable cues to associate personality traits with inanimate objects like devices found in an automated home. However, the choice of functionalities and how they should be expressed, were inspired by the descriptive attributes that are associated with these personality traits, such as Social and Active for high Extroversion or Goal-directed and Persistent for high Conscientiousness (Motzek et al., 2011).

- **EC Design:** We aimed to create an Energetic, Social, Creative, and Imaginative experience for our Extroverted and Cheerful design: it takes initiative to engage the user and does things automatically. It further makes suggestions, such as proposing activities based on the weather forecast and the schedule of the inhabitant.

- **CKC Design:** The Conscientious, Kind, and Calm design is intended to provide a more Trustworthy, Sensitive, Organized, and Responsible experience. It takes care to avoid bothering or interrupting the inhabitant, talks little, is diligent, and concerned with security. For example, it would show a list of the chores that have to be done or give an overview of events which took place while the inhabitant was gone.

To provide an example of how the experiences compare: in the EC design, as the user leaves the home, the Roomba gets in her way and guides her to the forgotten item expressing Assertive, Lively characteristics (high Extraversion). There it moves back and forth with playful sounds expressing Artistic characteristics (high Openness). In the CKC design on the other hand, the home directly drives to the wallet where it makes a single sound to express Goal-directed characteristics (High Conscientiousness).

5.3.1. Expressing Personality Through Design

To express personality traits through smart home functionalities, we considered multiple communication channels besides speech. For each scenario step, we considered the expressiveness of the various smart home functionalities, such as voice and audio content of the agent, motion of the vacuum cleaning robot, colors and dynamic light patterns of the lights. We then discussed the fit of our design choices to the intended personalities, comparing them to findings from related work.

We conducted five pilot sessions with co-workers and students in our department. In addition to experiencing our intended study setup they were asked for more detailed feedback on the prototypes. This informative pilot study revealed that the content of our voice output in our early designs overwhelmed the perception of the personality traits conveyed through any of the other implemented functionalities. As our goal was to create a balanced and coherent experience through the variety of involved functions, we reduced the amount of voice output and paid close attention to the choice of words to convey specific personality traits (Yarkoni, 2010). The voice output in the EC design included more content and words that are associated with family, friends, and social settings, as well as words that reflect intellectual or cultural experiences and creative functioning such as "meeting friends" or "listen to music" (Hirsh & Peterson, 2009; Yarkoni, 2010). The CKC design contained more content and words related to work, achievement and discipline, as well as to empathy, love, and affection such as "finish your tasks" or "you should go to bed" (Hirsh & Peterson, 2009; Mehl, Gosling, & Pennebaker, 2006; Yarkoni, 2010).

We also used different light colors and differently designed visual feedback as cues of the home's personality in its responses. The EC design uses bright and saturated colors, while the CKC design uses subtle hues (Ståhl, Sundström, & Höök, 2005). It also uses more visual feedback, such as reflecting the detected mood of the inhabitant with smiley icons to express its extroversion in addition to verbal feedback, while our CKC design only changes the light very subtly in response to the inhabitant's mood.

We played music in the waking up and in the going to bed parts of the scenario. While choice of music generally depends on personal preferences rather than personality, it can also be mapped to specific emotions (Dunker, Nowak, Begau, & Lanz, 2008). We took advantage of these associations and used more cheerful music for our EC design while using calmer music for our CKC design. We further took the music's lyrics into consideration to make sure it fitted with the home's personality.

5.3.2. Subjectiveness of Personality Design

It is especially important to acknowledge that the design of the home personalities in our study is subjective in nature. That is to say, we employed subjective processes to translate the intended personality traits into home functionalities, features, and actions. As such, although we may have designed a feature to fit our conceptualization of a personality trait such as cheerful, it is not necessarily (and indeed unlikely) that the feature would be universally perceived as cheerful by others. Our aim, however, was not to assess specific personality traits of a home, but rather to explore what it meant to design a home personality, and understand how the manifestation of personality traits as smart home functionalities and behavior would be perceived and interpreted. As such, the two contrasting personalities we designed served less well for the purpose of evaluating these two personalities, and beetter for the purpose of probing into the broader space of personality trait-inspired home behavior.

5.4. Methods

We created a usage scenario through an iterative design process which entailed typical daily activities, such as waking up or leaving the home, in which a person could potentially interact with a home. Again, our goal was to allow our participants to experience interactions with an agent-like smart home to invoke a reaction in them. To make the scenario immersive, we implemented a prototype in our research lab including a variety of different smart home technologies (positioned as indicated in Figure 5-2) using CasaCore for the communication with the devices. The setting for the study consisted of a space that was divided into a simulated bedroom, bathroom (see Figure 4), living room and hallway (see Figure 5). The bedroom contained a bed, a TV screen, a Kinect and a Philips Hue light. The bathroom included another light, a TV screen, a mirror and a camera above the mirror. In the living room a couch, a TV screen, a Kinect and a light were set up. The Roomba and another light were placed in the hallway.

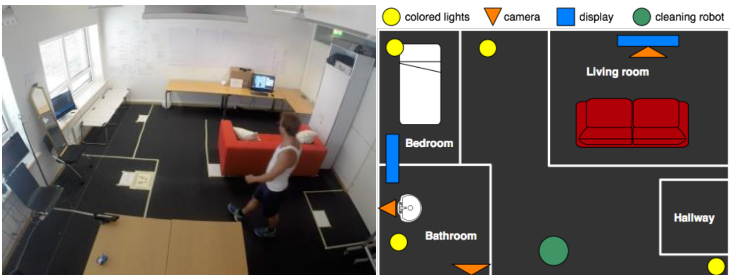

Figure 5-2: (Left) Top down view on our lab study setup; (right) floor layout of our lab study setup

5.4.1. Procedure

Forty-one participants were recruited through a University mailing list as well as through the social networks of the authors. Participants did not receive an incentive beyond snacks that were offered after the session. After being welcomed to the study and providing informed consent, the participants filled out a short preliminary questionnaire regarding their prior knowledge and understanding of smart homes as well as their own personality. They were then guided through the experience of the first personality variant. This guided experience was similar to user enactments by Davidoff's et al. (Davidoff et al., 2007). For their studies they created a room with paper prototyped probes to allow participants' to experience different usage scenarios. In our setup most of the functions of the home were actually implemented but augmented with some narration about the hypothetical context to create a more immersive experience. After experiencing the first home variant, participants filled out a second questionnaire with questions about it before experiencing the second personality variant along the same usage scenario. Finally, they filled out a third questionnaire which covered the same questions as the second, along with other questions that asked them to compare the home variants. The questionnaires can be found in Appendix F.2. Each session took between 40-45 minutes. The order in which the participants experienced the two variants was counterbalanced to avoid bias.

The usage scenario consisted of several situations of daily living that we designed to include potential interactions with the home.

1. Inhabitant lies in bed. The home wakes her up using music and lights, after that it presents information relevant to her day, such as weather or schedule.
2. She goes into the bathroom. The home detects her mood based on facial expression and reacts to it.
3. She goes to leave the home. The home reminds her of forgotten items as well as the weather forecast before she departs.
4. She comes back home. The home gives an overview about potentially noteworthy events that took place while she was gone.
5. She wants to watch TV. The home provides information about previous TV interactions as well as planned activities.
6. She goes to bed. The home adjusts the light and offers to set the alarm.

For each of the activities we designed two different variants to show the two different personality compositions using the design choices described earlier. A detailed table describing the steps of the study scenarios and the responses of the home design can be found in Appendix F.3. An example of mood tracking was done to give participants an idea of affective interactions. Inspired by the HappinessCounter (Tsujita & Rekimoto, 2011), a bathroom mirror (see Figure 5-3) that attempts to make the user smile every day, we selected the bathroom to provide this experience as well. While our prototype was developed to react dynamically to a user, such as to responding differently to different detected moods, for our studies we created a static version of the experience for each design variant, so that all participants would have a consistent experience.

Figure 5-3: Bathroom (left) and bedroom (right) setup

We guided participants through the experience and made it more graspable by telling them the story of the usage scenario. In both variants we told them for each activity in the scenario what steps they had to perform next and provided them with additional context, for example, "Now you go to the bathroom and since you haven't slept very well you look tired into the mirror." In the beginning of the study we clarified that these instructions spoken by the experimenters were not part of the home's character, and only given to help them understanding the scenario better. Then the home would respond accordingly to the personality variant, e.g. showing a visual of the detected mood and adjusting the light color in the CKC design or additionally commenting on the detected mood and offering to cheer one up in the EC design. We also verbally added comments about additional behavior executed by the home that we did not prototype, such as the preparation of coffee while they were taking a shower or that it opened the windows and turned down the heating after showering.

5.4.2. Data Collection

To capture participants' responses, we took notes on their behavior while they were walking through the scenario variants in addition to administering the questionnaires. The preliminary questionnaire covered demographic questions and asked participants about their existing knowledge about smart homes. For example, we asked them to write down their definition of what a smart home is and asked whether they had used automated home functionalities previously to assess whether their understanding captured the notion of automation and multiple devices. Personality traits were found to be crucial to the acceptance of systems with social components, as, for example, shown with social networking sites (Rosen & Kluemper, 2008). Thus, we also asked them to answer questions that would allow us to assess their personalities so we could take their own personality traits into account in our analysis. For this inquiry we used the BFI-10, a shortened version of the Big Five Inventory (Rammstedt & John, 2007).

To capture their impressions and opinions of the first smart home design experienced, they answered a questionnaire after the first scenario (see Appendix F.2), prior to experiencing the second design. This questionnaire included questions about what they liked and disliked in the experience, and how they assessed the personality traits in the home variant they had just experienced. To do so, they rated the following attributes representing high and low traits of the Big Five personality traits on a five point Likert scale: Energetic, Social, Creative, Imaginative, Insecure, Moody, Trustworthy, Sensitive, Organized, and Responsible (Motzek et al., 2011). We further asked them how much they agreed with several statements about trust, privacy, personal preferences, and general experiences, and to explain their ratings. After experiencing the second design, they were asked the same questions as well as additional questions comparing both experiences. In this last part they were also asked to choose and rank various personality attributes from a comprehensive list that they would like in smart home, and to explain their choices.

5.4.3. Participants

Most participants (68.3%) were between the age of 20 and 29, 24.4% between 30 and 39. Only two participants were over 60 and one under 20. We had a majority of 63.4% male participants. 46.3% of our participants were employed, 53.3% were students, and 0.4% indicated something else. 68.3% had a technical background. The bias towards male participants with a technical background has to be taken into account for the generalizability of our results. Most participants lived either with one (43.9%) or more other people (36.6%); only 19.5% lived alone. Those who lived with others shared their homes with their partner or family (46.3%), with friends (17.1%) or other people (17.1%). This was important for us as we were interested in whether participants would raise concerns about the use of our interface concept in a multi-user setting.

Less than 5% of our participants stated that they did not know what a smart home was. The majority provided us with a definition that described a smart home as a home which performs tasks or regulates the home infrastructure (e.g., heating) automatically or as a home that consists of an interconnected network of programmable and (remotely) controllable devices and sensors. Another type of description included the notion of adaption and support of inhabitants' daily needs, such as with the help of artificial intelligence. Some participants argued that a smart home should be oriented towards a goal, namely to optimize energy consumption and thus contribute to sustainability, or to track the inhabitants' health. Despite their knowledge, the majority (75.6%) reported not to use any sort of automated functionalities at home. Only 9.8% mentioned using the Philips Hue Lighting System or the Roomba, which was also mentioned by 9.8% of our participants. Using automatic blinds or motion sensors triggering lights were reported by 4.9% each.

Only four participants reported to use more sophisticated appliances or settings (e.g., Synology NAS with Python Home Assistant).

5.4.4. Analysis

The questionnaire items were answered using a Likert-scale (strongly agree, agree, undecided, disagree, strongly disagree) and we performed a Mann-Whitney-U rank sum test (within-subjects unless stated otherwise) to evaluate if the difference in our participants' answers was statistically significant or not ($p<.05$). We further analyzed the open-ended responses by looking for the frequency of words as well as evaluating them qualitatively through open coding. The word frequency was based on word stems using the Porter stemmer (Porter, 1997) to make sure that related words were not treated separately.

5.5. Results

We begin our findings by describing participants' perceptions of the two different designs and which personality traits they reported to consider desirable or undesirable in a smart home.

5.5.1. Attribution and Preference of the two Home Designs

While the main purpose of the two different designs was to allow participants to experience two noticeably different smart home types, we also looked at whether they correctly attributed the personality traits that we designed for. We found indeed that neither of our designs was associated with neuroticism which was the one personality dimension we had excluded. In terms of people's correct association of the home and the intended personality, a correct attribution was found for the extroverted design with statistically significant results ($p=.039$). However, we did not find significant results when considering people's responses after having experienced the first home only. Thus, a correct attribution of personality traits to a specific design of a home's interaction might be difficult to achieve, but it might be possible once people become more familiar with what they could expect from such a home and the ways in which it could vary. This finding was also backed by the comparative comments they made, like A16 commenting that the

Extroversion was the most recognizable aspect in the designs.

EC design was *"more lively and social"* or B17 stating that the CKC design *"was much gentler, and more helpful."* The fact that we only found a reliable, correct attribution for extroversion is in line with prior work in which it was also the most accurately observable dimension (Lippa & Dietz, 2000).

Overall, participants preferred the Calm, Kind, and Conscientious design over the Extroverted, Cheerful one.

After experiencing both scenarios participants were asked which home design they would enjoy to live in more. 61% chose CKC and 39% chose EC. We were curious as to whether this tendency towards the CKC design would also show if participants could not compare the design. Therefore, this question of how much they would enjoy living in the demonstrated home variant was also asked after the first impression. When analyzing only the data from the first impression we found a statistically significant difference ($p= .034$) in participants' ratings. Most participants (61%) stated that they either agree (42%) or strongly agree (19%) that they would enjoy living in a home demonstrating the CKC design. However, a majority (65%) were either undecided (30%) or disagreed (35%) that they would enjoy living in a home demonstrating the EC design. Thus, people perceived the CKC design in general as more enjoyable.

5.5.2. Chosen Desirable and Undesirable Personality Traits for a Home

Trustworthy, Organized, and Responsible were the most preferred characteristics for a home.

After being presented with both smart home variants, participants were asked to choose and rank personality traits from a list of 20 adjectives representing both high and low characteristics of the Big Five dimensions (Motzek et al., 2011). We clustered and ranked the most popular choices by taking the order of the rating into account using CombMNZ (Fox & Shaw, 1994). The derived results are represented in Figure Table 5-2 which shows the five most chosen desirable (green bar) and undesirable (red bars) adjectives and to which dimension they belong. The number following the adjective and size of the bar represent their score on the combined ranking.

The three most chosen and highly ranked adjectives were Trustworthy, Organized, and Responsible; all adjectives representing high Agreeableness and Conscientiousness. Inflexible and Aggressive, both attributes representing low Agreeableness, as well as Disorganized and

Irresponsible, representing low Conscientiousness, were four of the five mostly chosen and highly ranked adjectives for undesirable traits. Interestingly, these attributes were within the same two dimensions that the desirable attributes represent. Our interpretation for these results is that the design of these two dimensions is especially important for a successful user experience of a smart home agent interface. The major interest into these two attributes might also provide further explanation why our CKC design was preferred when comparing across the two experiences.

Table 5-2: Desireable (green) and undesireable (red) traits

	high trait score	low trait score
Agreeableness	trustworthy (100)	inflexible (100) aggressive (87)
Conscientiousness	organized (94) responsible (81)	disorganized (95) irresponsible (72)
Openness	imaginative (74) creative (70)	
Neurotism	moody (81)	
Extroversion		

desirable trait (ranking score) — undesirable trait (ranking score)

Imaginative and Creative are both traits representing high Openness and what we tried to convey in our EC design. They were less preferred than those ranking high on Agreeableness and Conscientiousness, just as our EC design was less preferred than our CKC design. Moody, an attribute for high Neuroticism, was frequently chosen as undesirable, which provides further evidence that this dimension should not be emphasized in the personality of home agent interfaces. Participants did not choose attributes that represented traits on the Extroversion dimension as either desirable or undesirable traits in a home.

5.5.3. Influence of Participants' Personalities

Earlier work indicated that people can recognize whether a personality trait demonstrated by a computer is more or less similar to their own and felt more attracted to those more similar (Moon, 1996). Thus, we were interested if a participant's own personality had an effect on how they perceive our home designs or which personality traits they chose. In our study, we could not find a strong influence from the participant's own personality on the perception of the home. When looking at whether participants' personalities influence the choice of desirable and undesirable traits in a home we found a statistically significant difference only for a few of them. For example, the 35 participants who chose Trustworthy as one of their top five desirable attributes tended to be more extroverted (>=4.5) than the six who did not, according to our analysis of their responses to the BFI-10 questions. Looking at the different personalities among the participants, we found some significant differences: thirty people ranked high on Conscientiousness (>4) and showed a higher interest in the home being Responsible, which itself is a high Conscientiousness attribute. The thirteen people that were less neurotic (<=1.5) had a stronger dislike for a Disorganized home.

Our study indicated only very little effect of the participants' personality in their choices for a home's personality.

It is beyond the scope of our exploratory work as well as our abilities to analyze exactly why individuals with certain self-reported personality attributes expressed preferences for specific personality qualities in a home. However, these findings serve to illustrate the more general point that there is no universally appealing home personality. Furthermore, they suggest that assessment of inhabitant personality might be useful in designing a home that provides a more appropriate, comfortable, and pleasant experience for its inhabitants.

5.5.4. Interacting with the "Personality of a Home"

We looked further into participants' responses to our designs and their comments to learn how the home's personality affected people's perception of the home. We discuss those findings from our exploratory study along three themes: how participants reacted to the proactive behavior our smart home experiences demonstrated, the perception of social and affective characteristics of our designs, and participants' opinions of creativity in smart homes.

Proactive behavior causes fear of required interventions

Most participants stated that they would enjoy living in the CKC design, the home that was designed to demonstrate less proactivity. They were undecided about whether they would like to live in the EC design which showed more proactive behavior. To learn what design choices influenced those differences in responses, and to gain understanding about potential underlying reasons, we analyzed the qualitative comments that participants provided along with their rankings.

The CKC design was perceived as organized, as well as gentler and less offensive than the EC design. Furthermore, the suggestions the CKC home made were perceived as being less strong than in the EC home. Participants reported that the questions the CKC home posed (such as whether to set defaults for the future and adapt the home to their specific needs) made them feel in control. This customizability and transparency in the configuration was perceived as helping them save time and mental effort, for example: *"It helped me spare energy thinking [about] stuff like 'should I take the umbrella with me'"* or *"[it] allows me not to waste too much time on unnecessary things."* The EC design, on the other hand, was sometimes perceived to be too bossy, aggressive, and impersonal, as expressed in comments like, *"I was pushed too much into a pattern, things were too automated."* There was a subtle difference in the perception of the home caring about them versus the home commanding them. For many participants, the suggestions in the EC design were simply too numerous. The feeling of being pushed too much into a certain behavioral pattern was associated with a loss of control. Participants reported feeling almost remotely controlled and influenced by the activity choices the home proposed to them. Multiple participants mentioned that they would not like to be the constant focus of the home's attention, especially if they lived with other people in the same home.

CKC design made participants feel more in control and disliked being the constant focus of the EC design's attention.

Required interventions reduce trust

The qualitative responses also highlighted issues of trust in a home. For example, we asked participants whether they would "trust the home to execute things the way they want in the future" to assess their belief whether the home could fulfill their needs. In order to learn whether they would be afraid of a control overhead, we further asked whether they thought they would "have to intervene in the home's actions frequently." Although not statistically significant (p=.12) we found a tendency towards trusting the CKC design more (M=4.07) than the EC design (M=3.73) as well as a slight tendency towards feeling less that they would have to intervene frequently (p=.09) in the CKC home's actions (M=2.71) while being undecided about it for the EC home (M=3.07).

Higher level of proactivity of the EC design makes people concerned about losing control.

These two aspects might be related and hint further at the problem mentioned by many participants, namely that they did not feel like they were entirely in control in the EC home. They stated that if they had to intervene frequently, it would imply that the home could not choose the right actions to perform on behalf of them and thus, would not be in line with their own intentions. In our designs, proactive actions were more numerous in the EC design compared to the CKC design. People were concerned that the EC home in particular might not be able to adapt to nonstandard scenarios and that a home might not be able to cope with all the different possible actions required to make appropriate predictions, based on the user's preferences. This perception is especially interesting considering that neither home in our study actually exhibited any learning during the scenarios. The CKC home asked more questions to confirm the user's intention as a way to customize and configure the home to a resident's needs. While we thought that participants might object to clarifying or confirming questions, many participants actually mentioned in the open comments that they liked how the CKC design asked those questions to confirm proposed actions.

Social and affective behavior need comprehensible reasons

In our observations as well as in the comments it became clear that participants took issue with mood-dependent reactions of the home. Especially when responding to participants' negative emotions, such as sadness or anger, they disliked the home's responses and wanted a way that the home *"could be set to totally shut up"* (B2) and they did not want the home to replace other humans or to act as a flatmate who *"tries to figure out what mood I am in"* (B14). This theme will come up again in our work specifically targeted at learning about perceptions of emotions in the next chapter.

Feeling uncomfortable about social interactions

Applications increasingly incorporate information from social networks, for example in search results or popular events in social circles into personal calendars. We included a similar scenario in our EC design in which the home recommended meeting up with some friends. The home offered to coordinate the meeting by finding a time that suited the participant and her friends, and also to get in touch with those friends. Several participants expressed discomfort about the idea of the home reaching out to their friends. They indicated that they did not want any social interaction that included a computerized agent and they felt that such interaction was unnatural. Even slight incorporations of social interactions like wishing a nice day were perceived to be feigned and undesired by most participants. For example, A15 said *"I think this 'I wish you a nice day' [coming from the home] is somehow phony, because it's a machine."* Only one participant reported liking these interactions; B1 reported: *"In case I live alone, I have somebody that talks to me and, if needed, cheer me up."*

Mediation of social interactions was undesired and perceived as unnatural.

Affective awareness perceived to be unnecessary

In general, designing for affective interaction, detecting as well as demonstrating emotions, proved to be challenging. Several participants found the mood detection component of the home unnecessary saying that they knew their mood on their own, and that they did not understand why the home would need to be aware of it. Others went further and claimed that this functionality would make their mood and daily activities worse, saying for example that *"it reinforced my bad feelings"*

Reasons for why a home might need to know about its inhabitants' emotions were unclear and thus perceived as uncomfortable.

(B1). The fact that they felt being watched by the home made them uncomfortable about the mood detection, referring to it as being "*strange*" (A17) and "*creepy*" (A15). However, in a home that conveys personality in a more sophisticated way the reaction to emotions could be conveyed more subtly and thus potentially avoid such a perception. For example, a home could decide to bother the user less with notifications if she seemed more irritable, or point out non-urgent problems only when the user seemed calm.

Human-like behavior needs to be predictable.

These findings relate to those we previously mentioned about undesirable home personality traits, adding to the evidence that certain emotional and social behavior is unwanted. The personality trait Moody, an attribute highly representing Neuroticism, was chosen frequently by the participants as an attribute they did not want in their home. Participants did not want a home that was itself moody, or that responded to mood dynamically: *"I want the same good advice every time, no mood-dependent quality of advice."* (B4) and *"I would rather have an inactive smart home than one that is introducing a bad mood"* (A18). Related to this, many participants did not want the smart home to be human-like in the sense that human personality traits may introduce mood dependent reactions. Predictable behavior was a higher priority than human-like behavior. Surprisingly, in a study of various personalities in a robot in a public setting, Gockley et al. (Gockley et al., 2006), found that "moodiness" could potentially encourage first time users to interact with a system as it might make it seem more interesting. This points to interesting open questions about how personalities in such systems should be designed to match the space in which they are embedded as well as the target users that they intend to support.

Creativity desired once a home is reliable enough

If perceived to be reliable, creativity could be considered as a sign of being "smart."

Although many participants had strong feelings about not wanting to have a social relationship with their home, and a dislike of traits that were unique to humans and atypical of technology, such as unpredictability, several participants still expressed a desire to have a home that had *"social and energetic traits [which] make the home much more lively"* (A21). They further agreed that a smart home should also be imaginative and *"creative to actually improve the daily workflow"* (A18). Some participants did not want the home to simply obey their orders but to propose creative suggestions according to an inhabitant's lifestyle: *"I see the smart home as a tool which can be used to improve your daily workflow so it has to be creative and imaginative in the sense that it checks things you have not thought about"* (A18). Thus, participants were interested in a home that could support them intelligently in situations in which they do not care to or do "not want to be smart" themselves. We can see that there is an interesting tension between predictable behavior and the wish to be creatively supported with helpful suggestions.

Also based on the order of the ranked desirable attributes, we can see that Trustworthy, Organized, and Reliable were on top, but followed right after by Creative and Imaginative. It might indicate that once systems like smart home agents manage to achieve to satisfy the first three attributes, factors like Creativity might become more important and desirable. This line of thought was also illustrated by A16: *"[A smart home is] only useful if it works nicely and supports me well with daily stuff and then we can start making the AI more human"* or B6: *"it has to be trustworthy, that's kind of a precondition. But as soon as this is a given, I want it to be more creative and imaginative than I am, otherwise there is no added value."*

5.6. Discussion and Implications

Addressing the various tensions in design is a very challenging task. In the following section, we provide some ideas for potential roles that an agent in the home might take on and how they could manifest in design. It is important to note that these suggestions are constrained by the design of our study and by characteristics of our study population. Most importantly, these suggestions are drawn from the perceptions and responses of people who have little or no experience of living in a smart home. Therefore, they should be considered novices whose perspectives would be most comparable to new inhabitants of such homes. Additionally, our findings were derived from initial responses of participants' first impressions of our prototypes in a lab environment. Thus, we did not capture the potential changes of attitudes and comfort that might arise even after a short duration of living with such a technology in one's own home. While they may be less applicable to longtime smart home inhabitants who already have a strong understanding of and trust in their smart homes, they are of greatest relevance when considering how to provide a positive experience for new inhabitants. It further provides input on how to make smart homes more appealing and lower barriers for potential inhabitants besides being of general relevance for the addition of personality-based design to existing smart homes.

5.6.1. Homes Need to Allow Inhabitants to Develop a Trust Relationship

The results and interpretations we discussed seem to underline the known tension between feelings of control in interaction with automated systems and perceived comfort by having the home take care of certain tasks. The overall consensus may be summarized with the following remark: *"It didn't feel like a private environment. More like I'm at home with a friendly stranger"* (B16). The home talking back to the user and commenting on them made them feel more observed despite it being helpful. Subtler ways of communication, potentially only non-verbal could help easing this problem. In the next chapter we will discuss using expressions of emotions for this purpose.

There is a fine line between feeling supported and being patronized.

Besides illustrating an uncomfortable interaction with an unknown person in an intimate space, this comment hints at a potential privacy problem. After experiencing both home personality variants, people remained undecided whether they would feel comfortable with their privacy in the EC home because they perceived it as crossing social boundaries. Yet, they did not express those concerns for the CKC design. They felt okay about the support and assistance the CKC design provided, but perceived the EC design to act in a parent-like or patronizing fashion. For example, the recommendation to go to bed early was perceived as *"sound[ing] like 'mom'."* This kind of patronizing behavior led one participant to report that he *"didn't feel like [he was] the owner of my apartment"* (B17).

Allowing home and inhabitants to "get to know each other" might increase feeling comfortable later on.

In some way, we could think about the smart home agent as a flatmate who moves in and is instantly given access to all the functions in the home, the data we own and that passively tracks our conversations all day long. For an actual flatmate whom we do not know well yet, we would give the trust relationship time to develop before opening up and giving access to all of this. Designing for a phase with limited proactive behavior and a dialogue to "get to know each other" could be beneficial for inhabitants to feel more comfortable about the autonomy and proactivity that a smart home agent might exhibit later on.

5.6.2. Homes Need to be a Predictable, Organized Addition to the Household

A very different theme we found in participants' qualitative responses was suggestions on where such a smart home could come into play in interfamily life, such as being a potential mediator between the household members: *"The house could remind housemates about things they should do (washing the dishes,...), but in the end it is the housemate that has to do it."* (A3). Because the home is not an actual person, a person might not develop as negative a response towards it as they might towards a flatmate who was always reminding him to do the chores. The home would need to support a household's unique set of values. For example, in a shared flat it might remind flatmates about the required chores that they previously agreed upon, while in other homes such a behavior would interfere with household dynamics and the way they would like to communicate with each other.

Home could act as a neutral support of a household's routines.

5.6.3. Homes Need to Propose, not Impose Clever and Creative Suggestions for Support

Smart homes do not necessarily need to be understood as homes that are 'intelligent' themselves, but as systems that offer resources to augment inhabitants' intelligence (Taylor et al., 2007). This type of technology allows and supports people in making their own decisions. Similarly, our work identified participants' expectations of the creative, even imaginative, behavior of such technologies. They do not want their home to be an unknown person with a mind of its own, but rather an intelligent helper who supports them to complete everyday tasks better or quicker while knowing when to leave inhabitants alone. The notion of a butler as a smart home assistant is quite common in smart home research. While a butler may act invisibly in the background (Hamill & Harper, 2006), this might be problematic when the algorithms determining the home's behavior or trying to resolve ambiguities need more data. Hamill and Harper (Hamill & Harper, 2006) drew analogies

To provide value, a home needs to act as a clever assistant without forcing decisions upon its inhabitants.

between HCI and historic master-servant interaction to inform the design of speech-based interfaces in smart homes. Their work was mostly concerned with the nature of how instructions were expressed and they identified that a lack of contextual information in the instructions of the mistresses to the servants was often the cause of ambiguities and misunderstandings; due to the nature of the historic relationship the servant could not ask for clarification. In a butler-like smart home, people might expect the same reserved behavior from the agent interface. However, a role in which the home could reasonably ask back with clarifying questions might be more promising, eventually lead to less required interventions and thus allow for a better establishment of trust. As our study demonstrated, participants were surprisingly receptive to an open dialogue that entailed conscientious confirmation on the part of the home.

5.7. Summary

We explored in this chapter how interactions with future smart homes could be facilitated by abstracting the complexity of various devices, functions, and potential configurations to personality traits. We created a lab setup in which study participants experienced two different designs, an extroverted and cheerful home as well as a dutiful, calm, and conscientious home. We learned that a home's proactive behavior can be perceived positively and that creative, surprising actions by the home might even be attributed to its intelligence. However, demonstration of reliability was still the most important characteristic for a comfortable interaction. Additionally, we found a sensitive boundary for what areas of life a home might proactively address: acting autonomously in the mediation of social relationships might be off limits in agent interfaces for the home. This might indicate a potential limit to the "personifying" or "humanizing" metaphor. In the following chapter, we look at such boundaries from another angle, by pushing the metaphor even further and giving an object in the home the notion of demonstrating its own emotions.

Chapter 6. Emotions: Explore Expressiveness[6]

Similar to our exploration of personalities in human-home interactions, in this last approach we also aimed to elicit human-like characteristics to understand more about potential use cases for them. This time we push the metaphor even further to learn more about the limitations of the "personalization" concept.

This work has been carried out during an internship at Microsoft Research. As such it has a considerably weaker relationship to our early studies of smart homes "in the wild" and our literature review. However, despite this disjoint, it can be considered as an extension of themes that emerged in the previous chapter, such as the expressiveness of proactive technologies and perception of agency in domestic technologies. Thus, this chapter focuses on how people would react to the home, or rather the objects therein, if they demonstrated having their own emotions, and if or when this would be appropriate. To learn about this provocative concept, we conducted an MTurk study as well as a lab study in which participants experienced a piece of furniture designed to convey emotions through colors, patterns and haptics, EmotoCouch (see Figure 6-1). Their responses to our prototype allowed us to learn how emotions could be used for communication with a smart home, the limitations to our concept, as well as use cases of interest.

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[6] Based on:

Mennicken, S., Brush, A. J. B., Roseway, A., & Scott, J. (2014). Exploring interactive furniture with EmotoCouch. In *Adjunct Proceedings of the ACM Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '14)*
http://doi.org/10.1145/2638728.2638846

Mennicken, S., Brush, A. J. B., Roseway, A., & Scott, J. (2014). Finding roles for interactive furniture in homes with EmotoCouch (pp. 923–930). Presented at *"HomeSys" workshop* and in *Proceedings of the ACM Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '14)*

In this chapter we first describe the underlying models of emotions and the related work we used to design for emotions in an inanimate object. Then we describe how we created the physical prototype as well as how we conducted our studies. Finally, we conclude by discussing implications from our study results.

Figure 6-1: EmotoCouch in a living room environment

6.1. Motivation and Approach

Picard (Picard, 1997) found that in order to function effectively, a system has to be able to process users' emotions. To probe on participant reactions to a mood-responsive home, we included an example of a potential mood-responsive interaction in our scenario. People also attribute emotions to the systems they interact with even if they are as simple as an automatic door (Ju & Takayama, 2009). Playful examples that have explored reactions to emotive objects are Jealous Furniture (*prntscreen | Jealous Furniture*, 2008) in which users' online behavior caused the furniture to demonstrate emotional responses. Our own prototype EmotoCouch looks at how inanimate objects can demonstrate human-like feelings through colored lights and haptic feedback. This is a different approach from our work on personality in smart homes in which we did not design the home to express feelings or emotions, but only to manifest personality traits in its functioning and interactions with the participants.

An important component of human interactions and personalities is emotion and how it is used for communication. But even in non-verbal interactions with inanimate objects or technologies, certain emotional attribution carries over, and users' emotions are also influenced by the behavior the object or technology demonstrates. To learn about the emotional component of interactions with technologies in the home, we wanted to choose a representative object for things we are inherently surrounded with in our homes and thus, picked furniture for our prototype EmotoCouch. Prior research found that characteristics of a piece of furniture can have an effect on people using it and how they perform in certain tasks. For example, a study by Kille et al. (Kille, Forest, & Wood, 2013), where people sitting in stable or unstable chairs judged the stability of couples' relationships, found a correlation between the chairs' stability and the participants' ratings. Rather than focusing on a specific use case or application, we decided to explore furniture that expresses a range of emotions, to learn how people react to the concept of emotional furniture, and in what context would they want their furniture to express a particular emotion. This would allow us to assess to what extent inanimate objects that a smart home consists of can leverage emotional language in their communication.

Emotions are attributed to objects as well as affected by interactions with machines.

6.2. Design Inspirations from Related Work

Our design choices for EmotoCouch's emotions were informed by previous research on emotional models, emotional associations with color, texture and haptics, and interactive objects. Although our work can be categorized as affective computing, we currently do not focus on reacting to people's emotions or how we can sense or guess them.

6.2.1. Emotional Models

A substantial body of research looks at how to conceptualize and classify emotions, e.g. (Bradley, Greenwald, Petry, & Lang, 1992), (Ekman, 2008), (Plutchik, 2001), (J. A. Russell, 1980). We found the Circumplex model of affect introduced by Russell (J. A. Russell, 1980) the most useful framework for our purposes. This model explores the association of emotions along two dimensions: pleasure-displeasure and arousal-boredom. The first dimension valence describes the degree to which an emotion is considered positive (pleasure) or negative (displeasure), while the second dimension, arousal, describes the associated level of energy from low (sleepiness) to high (arousal). Figure 2 shows how Russell mapped a wide variety of different emotions onto his Circumplex model. To explore and prototype a diverse set of emotions, we picked six emotions inspired by Ekman's basic emotions (Ekman, 2008) that cover the four quadrants of the Circumplex model (see boldfaced emotions in Figure 2): Excited, Happy, Calm, Depressed/Sad, Afraid, and Angry.

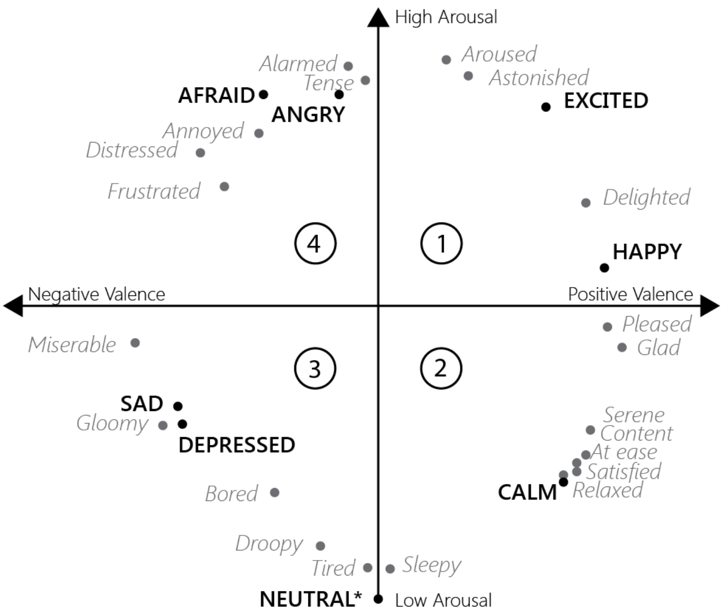


Figure 6-2: Circumplex model with selected emotions bolded.
** We defined Neutral at neutral valence, low arousal*

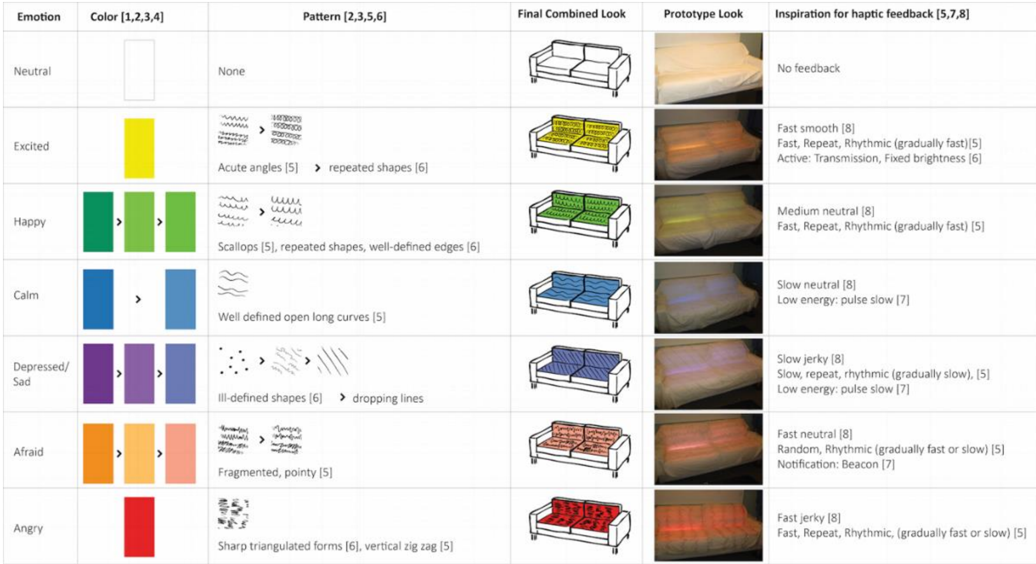
6.2.2. Emotional Associations of Perceivable Cues

Many researchers have studied associations of emotions with different kinds of cues in isolation (e.g. color, movement, texture, sound, or haptic feedback) [e.g. (Choi, Pan, & Jeung, 2007), (F. Davis, Roseway, Carroll, & Czerwinski, 2013), (Hupka, Zaleski, Otto, Reidl, & Tarabrina, 1997), (J.-H. Lee, Park, & Nam, 2007), (Lucassen, Gevers, & Gijsenij, 2011),(Ståhl et al., 2005),(Terwogt & Hoeksma, 2010),(*Tactile Allegory*, 2013)]. In the following section we describe how we built upon their work in order to achieve our goal of expressing emotions in furniture. Table 1 shows specific influences of different research on our designs.

We chose color as an emotional cue because considerable research has shown that colors evoke associations with emotions in people. We ground our color choices primarily on work by Hupka et al. (Hupka et al., 1997) who studied cross-cultural color associations, as well as Stahl et al. (Ståhl et al., 2005) who studied emotional expressiveness through colors and patterns in text communication.

Several pieces of research led us to include visual patterns as emotional cues in our designs, and explore the effect of tactile cues through haptic feedback. Lucassen et al. (Lucassen et al., 2011) found the psychological response of their study participants was strongly affected by adding texture to color samples. Davis et al. (F. Davis et al., 2013) explored what textures, tactile feedback, and shapes in fabrics elicit emotional response in viewers. Choi et al. (Choi et al., 2007) studied how colored lights can be used to convey emotional responses in apparel types, using EL wire to create different looks. We also drew inspiration for the patterns from Tactile Allegory (*Tactile Allegory*, 2013), which explored combinations of shapes and colors, as well as the aforementioned work by Stahl et al. (Ståhl et al., 2005). Finally, Lee et al. (J.-H. Lee et al., 2007) studied how to convey emotions through physical movement and provide a framework including velocity and smoothness as characteristics for emotional associations.

Table 6-1: Conceptual design and refinements based on related work for each of the six chosen emotions resulting in the final prototype look



Emotion	Color [1,2,3,4]	Pattern [2,3,5,6]	Final Combined Look	Prototype Look	Inspiration for haptic feedback [5,7,8]
Neutral		None			No feedback
Excited		Acute angles [5] › repeated shapes [6]			Fast smooth [8] Fast, Repeat, Rhythmic (gradually fast)[5] Active: Transmission, Fixed brightness [6]
Happy		Scallops [5], repeated shapes, well-defined edges [6]			Medium neutral [8] Fast, Repeat, Rhythmic (gradually fast) [5]
Calm		Well defined open long curves [5]			Slow neutral [8] Low energy: pulse slow [7]
Depressed/ Sad		Ill-defined shapes [6] › dropping lines			Slow jerky [8] Slow, repeat, rhythmic (gradually slow), [5] Low energy: pulse slow [7]
Afraid		Fragmented, pointy [5]			Fast neutral [8] Random, Rhythmic (gradually fast or slow) [5] Notification: Beacon [7]
Angry		Sharp triangulated forms [6], vertical zig zag [5]			Fast jerky [8] Fast, Repeat, Rhythmic, (gradually fast or slow) [5]

[1] Hupka et al. 1997
[2] Stahl et al. 2005
[3] Tactile Allegory
[4] Terwogt & Hoeksma 1995
[5] Choi et al. 2007
[6] Davis et al. 2013
[7] Harrison et al. 2012
[8] Lee et al. 2007

6.2.3. Interactive Objects

Consumer products and previous work on interactive objects also inspired us. Mood lighting products by Philips (*Philips | Mood Lighting*, 2015) illustrate the power of colored light to set mood scenes. Nazbatag (*Karotz | Nabaztag*, 2015) shows the range of information, including e-mail alerts or weather forecasts that an ambient electronic device could display, while Harrison et al. explored how patterns in blinking lights convey information (Harrison, Horstman, Hsieh, & Hudson, 2012). More closely related, Jealous Furniture (*prntscreen | Jealous Furniture*, 2008) is a bookshelf and lamp that becomes envious of the amount of time a user spends online. These works, in conjunction with the emotional models and emotional associations of perceivable cues, provided the creative foundation for designing the cues for the six emotional states of EmotoCouch.

6.3. Concept and Implementation

To build EmotoCouch we purchased an IKEA KARLSTAD couch frame and built four custom cushions. This section describes how we tried to convey the intended emotions through colors, pattern, and haptic feedback. As part of our design process we experimented with various sensors to understand opportunities for triggering the display of emotions by the couch. However, as our initial study was a lab study, for simplicity we manually switched the couch to different emotions.

6.3.1. Colors

Each of the four custom-built couch cushions contains 160 embedded individually controllable LEDs for a total of 640 lights overall. These were sewn into each cushion in five rows as shown in Figure 6-3. To create an evenly diffused glowing effect (see Figure 6-1 or Table 6-1), we experimented with several different types of padding to cover the LEDs, including various makes of cotton padding and stuffing foam, before determining that an approximately 5-cm-thick densified polyester fiber for home upholstery purposes gave the best effect.

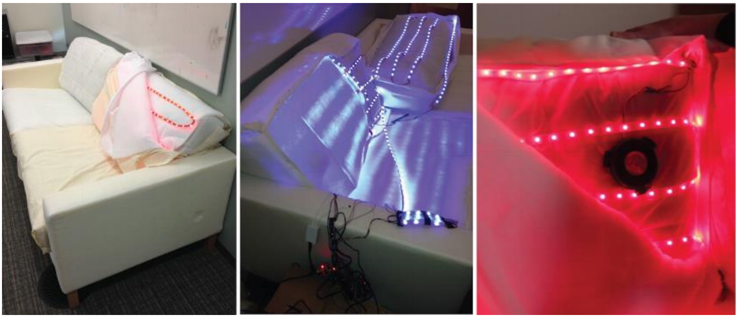


Figure 6-3: Couch cushion construction. All four cushions include LED strips and one has a bass speaker

The color for each emotion was initially inspired by related work and then refined in three iterations with 15 co-workers, in which we asked what emotion they associated with each color. Table 6-1 on page 210 illustrates the design changes of the colors. While literature suggested darker or desaturated colors for certain emotions, these were difficult to achieve with LEDs as light emitting sources. In our prototyping process we also experimented with a variety of dynamic light behaviors, such as pulsing, fading, or transitions between colors. For our lab study we decided to only use static single colors, as we wanted to focus on studying the emotional association of the chosen individual colors.

6.3.2. Patterns

We created different patterns on the cushion covers for each emotion based on related work as shown in Table 6-1. The initial patterns were also refined with our co-workers with the goal of maximizing the emotional association of a specific combination of color and pattern with a certain emotion. For example, a blue color with wavy lines was our chosen combination for the emotion Calm.

To explore technical means of changing patterns dynamically on the couch, we experimented with thermochromic effects. As illustrated in Figure 6-4, we stitched thin nichrome wire through fabric in distinct patterns and used a mix of screencast and thermochromic pigments to create those patterns visually. Once current is applied, the nichrome wires heat up and the pigments turn clear making the pattern disappear. By using very thin wires (0.08 mm) the pattern remained transparent, even when the canvas was backlit. Due to the amount of wire needed for the actual couch dimensions and potentially hazardous power levels that the resistance of the long wires necessitates, we decided to prototype the six designs with hand-drawn patterns (see Table 6-1 on page 210) and change them as individual covers manually on the couch.

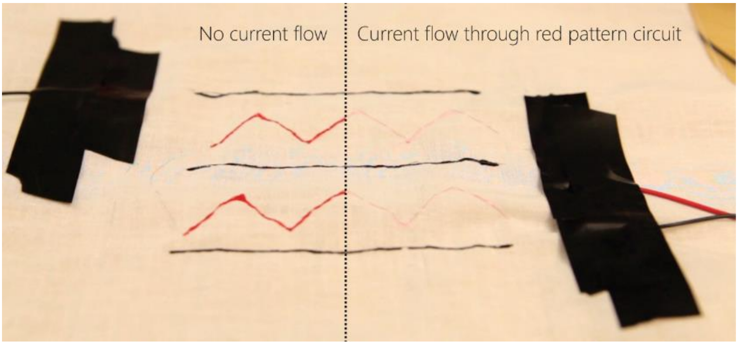


Figure 6-4: Changing a pattern dynamically

6.3.3. Haptic Feedback

We created haptic feedback by playing subsonic sounds using a 15W bass speaker (20-80Hz frequency response) embedded in one of the couch cushions (see Figure 6-5), which causes a person sitting on the couch to feel vibrations. We implemented haptic feedback using a .NET Gadgeteer FEZ Spider Mainboard that plays subsonic audio files stored on an SD card through a Gadgeteer music module. We designed six different haptic behaviors to convey slow to fast movements and smooth to jerky ones, inspired by related work on associations with physical movements to emotions (J.-H. Lee et al., 2007), e.g. a steady, repetitive, medium-paced drum beat for Happy or a very irregular, fast one for Afraid.

6.4. Methods

This section describes the goals and methods of our online survey and lab study.

6.4.1. Online Survey Method

To assess whether people associated the emotion we intended with the color and pattern combinations we chose we conducted an online survey. We asked participants to associate one or more emotions with a set of six plain color swatches, six colored couches, six patterns on a white couch, and six Color+Pattern combinations (see Table 6-1). For each picture we also asked them to optionally describe why they associated that emotion with the picture, and in what situations a couch might express that emotion. The sequence of the presented questions was counterbalanced to control for potential order effects.

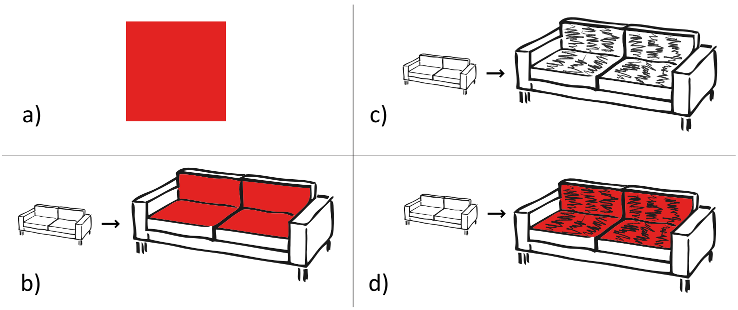


Figure 6-5: Examples for Angry of the four different pictures to which survey respondents associated an emoation: a) plain color swatch, b) couch with Color c) couch with Pattern d) couch with Color+Pattern. Participants saw pictures for each of the 6 emotions.

We recruited 138 participants (84 female, 54 male) using Mechanical Turk. Participants received a link to a SurveyGizmo survey and $0.50 on completion. As culture influences people's color associations (Hupka et al., 1997), we asked participants where they currently live and where they grew up and only included participants whose answer was the U.S.

to both questions. The median age of participants was 30 with a range from 18-61. We could not control the color consistency across the various participants' screens, but to reduce confounding variables, we included only participants who reported having normal or corrected-to-normal vision and who were not color-blind.

6.4.1. Lab Study Method

The laboratory study explored the physical experience with our prototype, how people interact with it, and the design of our haptic feedback. As furniture in households is often used by several household members and related work indicates that people's associations of colors and emotions change across age groups (Terwogt & Hoeksma, 2010), we recruited 14 parent-child pairs, with children covering the age ranges of 6-9, 10-12, and 13-15. The lab study was conducted in the U.S. with participants who live in the U.S. Children were 7 to 15 years old, with a mean age of 12 years. Parents were 30 to 54, with a mean age of 45 years. We had 5 father/son pairs, 2 father/daughter, 3 mother/daughter, and 4 mother/son.

Participants were first asked about their current emotional state and their favorite color. We then showed participants EmotoCouch in its Neutral state with a plain white cover. Next, they were taken individually to EmotoCouch, which was set to a specific emotional state, and asked which emotion(s) they associated with its appearance from our six chosen emotions, Neutral, or Other, and why. We repeated this for the six emotions, with the order Latin square counter-balanced across study sessions.

To evaluate the value of haptic feedback, we split lab study participants into two groups: Color+Pattern and Color+Pattern+Haptic which included haptic feedback in addition to the color and pattern. At the end of the study, the Color+Pattern group completed a haptic-only segment where they associated the six different haptic designs with emotions while sitting on the Neutral couch. To gather data about differences and similarities among family members, parents and children were presented with pictures of all emotion designs, and asked to collaboratively decide on their favorite, least favorite and associate each design with a single emotion. We concluded with semi-structured questions about interactive furniture in general.

6.4.2. Analysis

Participants' free responses on the survey and the lab study created a large amount of rich qualitative data – over 3000 notes. We began data analysis using the affinity clustering methods on a subset of notes from the lab study to identify themes (about 500 notes). Informed by these themes, two researchers independently coded a subset of free response answers from our online survey and lab study and then discussed them to agree on a final set of codes. These codes were then used to analyze all free responses independently and discussed to agree on a primary and (if appropriate) secondary code which were used for further quantitative analysis. A second set of codes was developed specifically for the color and pattern survey responses focusing on color preferences, frequently mentioned associations (e.g., "like spring", "like a still lake"), and whether participants liked or disliked the color or pattern. These comments were also coded by two researchers with disagreements resolved through discussion. In the following, MX refers to survey participant with ID X. For lab study we use PX, CX to indicate parent or child of pair X.

6.5. Results

The correct attribution of the emotions to the chosen design combinations is less important for the overall argument of the usefulness of emotions in the communication between the home and the inhabitants via individual devices, so we will only provide a summary of our findings leaving the details to the report attached in Appendix G.1.

6.5.1. When Should a Couch Show Emotions?

Based on the online survey and lab study free responses data we coded, we identified the emerging themes for situations when participants thought their couch might display an emotion, why, and how that could be used beneficially.

Couches React to Environment

Participants frequently mentioned the surrounding environment of the couch as a reason for the couch to display a design (18%, 141 of 778 comments). Participants focused primarily on the following four aspects of the environment:

1. **Activity Level:** E.g. M4: *"Just a normal, calm day"*, M3: *"It likes all of the activity going on in our house with the kids and animals."*
2. **Weather:** E.g. P5: *"winter time, when it's dark when it gets dark early, it's cold"*, M122: *"It would be afraid if there was a storm outside."*
3. **Time of Day:** E.g. C13: *"Early morning or late at night"*
4. **Physical Surrounding:** A particular place the design would fit (e.g. garden, beach). E.g. M133: *"I would feel that the couch would go well in a play room because yellow is a playful color."*

Comments often combined Activity Level with other environmental aspects. For example, M127: *"On a rainy day when someone was taking a nap on it"* or M79: *"Most days in my house due to the calm and quiet atmosphere."*

React to Resident (Co-dependent Couch)

Similar to how a family member or friend might react to the way you are feeling (e.g. offering comfort if you are sad), participants thought the couch might display a particular design in response to their emotional state. The couch reacting to the resident's state was mentioned in 10% of comments. Comments were made related to all the emotion designs, but most commonly when viewing the Angry and Depressed designs. For example, M110: *"The couch would look like this while I am fighting with an old friend or my family,"* and M94: *"when someone is crying nearby."*

To Encourage Certain Behaviors

A theme that emerged was the notion of the couch using its emotional displays to reflect certain behaviors in the home. These included accomplishments (e.g. M110: *"The couch would feel this way when I got a promotion at work. It is exciting and fun!"*), when the family is together (P8: *"Whole family is there and we are playing games and having popcorn"*) or proactively trying to change the mood. For example, P6: *"tell everyone to calm when everyone is home from work or school to calm people down before bed."*

Several lab study participants expressed ways emotional furniture could influence the mood or nudge to desired behaviors. These included helping them get into a certain mindset (P3: *"If it could sense that I'm tense, it would try and get me out of that."*), reflecting their actions (e.g. C1: *"It would make you think more about what you are doing, you wouldn't bring messy food and not clean-up after yourself"),* and reminding them of their schedules by waking them up (P11: *"Energetic type of color when I need to wake up"*) or making them uncomfortable (P7: *"It could encourage me to do something that I might want to do or might not have the energy"*).

The three themes described above all refer to emotional expressions as "service" to the inhabitant to increase awareness or provide a reflection of one's behavior. Interestingly, participants also described use cases which do not serve a direct purpose to them.

Couches like People

Many participants felt that a couch could convey emotions while it was being used. An overall 21% of comments (160 of 778) described designs appearing in situations when the couch was being used. Commonly mentioned situations were parties (M54: *"Maybe during a party at the house with people around"*), relaxing or sleeping (M58: *"When I am relaxing on the couch"*), watching TV, playing games (both physical and digital), or sitting.

Couches Dislike Abuse, Loneliness

Two types of negative situations that participants associated with the couch showing emotion were varying levels of abuse and being left alone. In 15% of comments participants mentioned the couch being mistreated in some way. These situations often featured pets (M22: *"definitely when the cat scratches it"*) and when too many people or children were overloading the couch (P1: *"If there's kids jumping on the couch"*). People also felt their couch would dislike being spilled on or being left messy (M55: *"I eat dinner while sitting on it and never clean up"*). Perhaps not surprisingly, the majority of these comments were made when looking at the Angry design.

Another theme, most commonly described for the Depressed/Sad design, was loneliness, mentioned in 8% of comments. Many people felt the couch would be unhappy alone, when it could not do its job (C1: *"everybody in the house stopped sitting on it or going near it"*).

Implementing Couch Awareness

Many situations in which participants thought their couch would show emotions seem possible to be sensed with existing technology including noise level and usage. For example, recent work by Cheng et al. (Cheng, Zhou, Sundholm, & Lukowicz, 2013) using pressure sensors under chair legs to detect activities shows one possible method to detect usage. Others require only a connection to the Internet (for e.g. the time of day, weather, or family calendar). Enabling the couch to react to the resident's emotion would be the most complex awareness to implement. This would require practical affective computing-based emotion sensors worn by family members or integrated into the couch. However, if the couch is integrated in the network of devices of the home, data could be merged to give it the knowledge it would need to react correctly.

6.5.2. How Emotional Should Furniture Be?

Autonomous or Manually Controlled?

While décor considerations mattered, a more actively debated question, particularly between by parents and children, was whether the couch should autonomously express its own emotions or be set manually to a desired state. Participants who expressed concerns with the couch being autonomous were mostly parents and preferred the ability to set the emotion/appearance of the couch. They were concerned about adding yet another "emotional being" in their household and did not want, as P6 said: *"one more thing you'd have to be sensitive to"* or to feel that they needed to spend time worrying about how their behavior might affect the couch, e.g. C7: *"I'm so used to have the couch as a piece of furniture and not thinking about how it's feeling and [that] stuff affects it."* Instead, many stated they would want the couch to be available to assist them, for example so they could set it to a certain design to help them relax.

In one of the biggest differences we observed between parents and children, more children liked the idea of the couch behaving autonomously. They suggested the couch might be an "emotional companion," being there for them. P11: "*if anyone felt a little not well, comforting them"* as well as something they would take care of, e.g. C1*:* *"You could start petting it to calm it down, cheer it up, pet it or sit there with it."* A few parents related to the idea that an autonomous couch would be more "service-like," e.g. it might be valuable for light therapy.

Only Positive Couches Please

Some participants said that they only want a couch with positive emotions (e.g. P3: *"Nobody wants your couch yelling at you"*). Mostly parents expressed interest in having the couch in a relaxing or soothing state. P11: *"After a long day at work and coming home, that blue one would feel really nice, very soothing."* Data from the survey shows a preference to associate emotions with Positive Valence to the designs. Out of all 1199 responses for combined Color+Pattern pictures, 58% were either Excited (20%), Calm (19%), or Happy (19%).

Some participants speculated about potential emotional transference and liked this idea if the couch was positive (C1: *"If the couch is happy, I'm happy, too"*), but expressed concerns for negative emotions (P6: *"Not angry, depressed, or sad. Since it can change your emotions. Emotional transfer is not good"*).

6.6. Summary

In this last chapter of Part 2 we pushed the metaphor of personification to an extreme by creating a prototype that demonstrates its own emotions. This way we were able to learn more about the limits of this metaphor and to learn how the attribution of emotions might be used for the home to communicate non-verbally and subtly with its inhabitants.

Compared to our work on using the notion of personality, the demonstration of human-like characteristics was not serving an obvious purpose: in Chapter 5 the demonstrated human-like characteristics were always serving the users. In this last chapter the couch was only serving itself by expressing its own emotions. This provocative approach worked well to elicit responses in our participants and to inspired them into interesting use cases or else to reflect on the dynamics of their households. However, for most adult participants it caused major concerns about having to take responsibility for this object. Thus, instead of arguing for the potential of giving objects their own feelings to serve their inhabitants, it should instead be considered as an indication for the potential to use emotions to create an awareness of what is happening within a home or to use a similar vocabulary that provides people with additional cues to create a mental model of how the increasingly proactive homes work.

Chapter 7. Conclusion

We started this dissertation by exploring and reviewing the landscape of smart homes, in research and industry, in which we learned about the importance of helping inhabitants with various backgrounds to interact with increasingly proactive homes. In the last chapters we explored potential ways to address this progression from automated to autonomously-acting homes through user experience design. The three different approaches probed into this design space of current as well as potential future smart home interactions to inform their design with user perceptions. This final chapter concludes this work by summarizing our research questions, goals, key findings and main themes, to then discuss what implications and open questions they suggest for the design and evaluation of future smart homes technologies.

7.1. Goals and Contributions

The overarching research goal of this dissertation was to learn how researchers and designers can improve the user experience of smart homes as they progress from acting upon user-configured automation rules to sensing and "thinking" agency, in order to support their inhabitants' lives. Our various efforts to reach that goal were split into multiple aspects:

7.1.1. Understanding the Context

Our goal in Part 1 was to learn more details about the user experience that we sought to improve and the existing work that we could build upon. The rich understanding of the various aspects of current smart home interactions, and potential future ones, in context derived from our research, can help to guide studies of and designs for this area of application. This objective was fulfilled by reviewing existing work and conducting empirical studies of current smart homes and their inhabitants.

We revealed themes and trends in related work through a structured literature review in which we analyzed a list of 131 papers, posters and reports and synthesized it with our empirical work, with observations from visits with smart home interest groups and with field trips with a smart home professional. In our empirical work we focused on the following two research questions:

RQ1: How does a smart home develop "in the wild" and how does it get adapted to inhabitants' everyday life?

RQ2: What roles do inhabitants take on and what are their individual challenges when interacting with a smart home?

These questions were addressed by conducting home tours and semi-structured interviews as a first step with 22 individuals (9 of them living in 7 different smart home households, 5 were in the process of planning a smart home, 7 were smart home professionals), and a comment-card based follow-up study with 6 individuals focusing on Passive Users. The results from the first set of interviews were analyzed using affinity diagraming, the second set using open coding and synthesizing the findings with the previous themes.

Contributions

- **Set of promising research directions and an updated vision of future smart home experience:** Derived from a formal literature review, which further provides a comprehensive overview over the current smart home research landscape, we presented and discussed the current challenges that occur within smart homes, to create an updated vision for future smart homes. This vision includes the need for future smart homes to better address the increasing complexity of domestic spaces (see Section 2.3.2 – Increasing Complexity and Quantity of Solutions) and support inhabitants in finding solutions that suit their individual needs (see Section 2.3.2 – Implication: Support Finding Fitting Solutions and Safe Testing of New Functionalities) to eventually enable meaningful automation technologies (see Section 2.3.1 – Meaningful Technologies).
- **Phased-based model of smart home development:** From our empirical work, we identified four stages for smart home development as well as the unique challenges that occur within them. Few other studies on smart homes "in the wild"

incorporated the user experience before the technology was introduced in the home. We identified that this planning phase, too, is crucial to be considered for improved user experiences. Additionally, we found the early phase after the installation, which includes many iterations of the functionality, as very challenging for most users and thus is an interesting topic with potential to be improved.

- **Set of roles of smart home users:** As different household members adapt such a home differently, besides looking at the home, we also identified a set of roles, including their characteristics and challenges, to describe what roles do inhabitants take on and what their individual challenges are when interacting with a smart home. While we found that Home Technology Drivers often enjoyed the configurations of their homes like a hobby, the group of Passive Users, who did not have the same technical skills and interest in this topic, were more limited in their benefits.

7.1.2. Probing Different Interaction Approaches

The challenge of interaction with increasing intelligence in homes and the potential for collaboration with smart homes (see Section 2.3.3) was our main theme for Part 2. We probed the design space of current and future smart home user experiences with three different approaches. This goal was achieved by creating multiple prototypes and studying their responses. The two research questions that focused on were:

RQ3: Can we increase intelligibility of mixed-initiative technologies by visualizing their effects using temporal metaphors?

RQ4: How do inhabitants react when including human-like characteristics in interactions with a home?

We addressed those questions by creating an interface integrating smart home data into a familiar calendar interface and studying it in the lab to prepare a field-researched case study in two households. The families collected data throughout a one-month long study, answered questionnaires before and after and were interviewed to learn about their experiences. We also created two more futuristic prototypes that incorporated human-like characteristics in the participants' interactions with them – demonstration of personality traits and emotions. In both cases we conducted lab studies. The personality prototype was tested with 41 individuals; the emotion prototype was evaluated with 14 parent-child pairs. Our investigations in this space allowed us to provide implications for the design of interface agents in the domestic context. The furniture prototype concept was evaluated with 218 participants in an online survey as well with 14 parent-child pairs in a laboratory study. These studies allowed us to provide insights about the potential of emotional expressiveness of objects in the home as well as suitable use cases for these.

Contributions

- **Insights about "in the wild" usage of our proof-of-concept prototype for a calendar-based smart home interface:** By conducting an "in the wild" study and embedding our prototype into its actual context of use, we learned about the potential of temporal metaphors for visualizing smart home data, as well as requirements for a successful implementation that would facilitate inhabitants' ease of integration. We found that tools already used in participants' everyday life could offer a good opportunity for integrating smart home data, which to most users is not constant everyday interest. We also found that using a temporal metaphor like a calendar could support the identification of behavioral patterns of the home and provide a more accessible interface, as compared to common existing interfaces.
- **Research directions for the use of human-like characteristics in smart home interactions:** Through our studies of our prototypes, we learned about the difficulties and the potential for human-like characteristics in smart home interactions. Our discussion of our findings points to multiple research avenues and provides an early understanding. Through this work we identified boundaries for using such metaphors, such as a skepticism towards the mediation of social interactions or the demonstration of the home's own emotions,

as opposed to simply using such metaphors as a means for expression.

- **Lessons learned for creating a vocabulary of human-like characteristics in smart home interactions:** The development of our prototypes taught us about potential ways to express personality and emotions in objects and smart home interfaces. While we could successfully convey multiple attributes, we also learned from those which failed, which will inform the design of future systems aiming to elicit them.

7.2. Limitations and Future Directions

Naturally, the presented work also has several limitations which we mentioned throughout the dissertation so that they can be taken into consideration when using our results and implications. We believe others point, however, to further open research avenues which we will discuss in this section.

7.2.1. Extended Functionality and Evaluation of the Smart Home Calendar

The duration of the field-researched case study of the calendar concept was one month only which is a long time compared to most lab studies, but still a short time in people's lives. A longer study would allow researchers to observe the usefulness of our prototype as it would capture changes of seasons, holidays, or other exceptions that require changes to the home's configuration. We described earlier that we could not address several known design guidelines for calendars, and our prototype was also not capable of incorporating the myriad of potential functions or appliances in the home. Thus, we could not fully address the issues that we identified in our empirical work, such as fully integrating the scattered devices of the home. More recent Internet of Things services, such as IFTTT or Smart Things, provide a more accessible abstract layer for an ever-growing number of various functions for the home. We believe that through the increasing popularity of those services researchers as well as consumers will be able to develop more integrated interfaces, covering a broader variety of functionalities.

How can a feedback interface be extended to configure and control the home?

Our interface only provided very minimal options to control or change the configuration of the home and no means to set up new automation rules at all. This was perceived as a major limitation and will have to be addressed in future. Allowing for control and configuration via mobile devices will introduce interesting questions about people's perceptions of having their "home on the phone" and related feelings of trust, privacy and safety. This is especially interesting when the home's behavior is more dynamic and learns from the inhabitants' feedback to adjust its own routines.

How can other interface components address limitations of the calendar metaphor?

We learned that a smart home collects an overwhelming amount of data and while the filters we implemented allowed us to reduce this to some extent, it was definitely not sufficient. Data needs to be cleverly abstracted to provide relevance to the user, especially for extended periods of usage. While our approach provided a complementary view to the most commonly-used metaphors of floor plans and category lists, it will not be suitable for all visualizations. Thus, the integration with other interfaces and other representation will be an interesting challenge in order to create a holistic and versatile smart home interface. One interesting new technology, that we believe will gain importance in the future, is wearable devices, as they might allow user identification and thus personalized customizations which were previously difficult to achieve, as phones are not carried on the body within the home (G. Olson & Olson, 2000). Such devices also allow users to have a personal, although small, screen display that can offer the preferred level of information that the user has interest in.

How useful is the calendar metaphor in different development phases and for the variety of stakeholders?

Our field study was conducted in two households who were in different phases of their smart home development: one household has reached a state of saturation while the other one was still iterating on its functions. But we did not formally investigate the usefulness of the metaphor in other phases, such as the planning phase which we consider to be crucial for setting the foundations of the subsequent experience of living in a smart home. Through the collaboration with smart home professionals, we learned about their interest in our interface. While we designed it for smart home inhabitants, they were interested in its use for their technical support of such homes. They described how it would allow them to trace back problems in the installation and have a tool that provides a glanceable overview to easily identify abnormalities. Another interesting population to study further are the home technologies drivers as they have an interesting DIY culture and share their practices in online forums and interest group meetings. Learning about how they iterate on the configurations of their homes and how other members of the household could be better integrated carries the potential to improve the smart home user experience for all inhabitants.

7.2.2. Facilitating Development and Studies for Long-Term "In the wild" Smart Home User Experiences

Through our work we learned that not only designing but also studying domestic technologies in their context is very complex. The highly unique and dynamic setup of each home that we evaluated demands a significant amount of effort to achieve a prototype quality that can be deployed and evaluated "in the wild."

What methods, tools, and frameworks are suitable for the design of smart home technologies?

We identified earlier that efforts to facilitate the development and the deployment of smart home technologies are an emerging theme. This can be found in research such as in Microsoft Research's Lab in the Wild (*Microsoft Research | Lab of Things*, 2015). But this can also be found increasingly in consumer products. E.g., Samsung's SmartThings (*Samsung | SmartThings*, 2015) and IFTTT (*IFTTT*, 2015) promote searching for solutions, as well as curated collections of existing solutions for others to reuse. Opposed to software which can simply be downloaded to one's machine, here might be some hardware changes or additions involved which imply a different, longer iteration cycle for development as well as adoption. Therefore, we believe it is important to create better methods, tools, and frameworks that can guide designers, developers and researchers to inform their work. Recently, Neustaedter edited a book that presents various methods of studying and designing domestic technologies (Judge & Neustaedter, 2014). The mere variety of these methods points to the difficulty of studying complex domestic lives to capture all interesting aspects. In our own recent efforts we focused on the transition between study findings and the design of smart home technologies by holding an interdisciplinary workshop to connect user-centered HCI methods with the sociological life-course perspective, to not only design for intermediate interaction with technologies, but also to find methods to design for their adoption and disposal (Mennicken et al., 2015).

7.2.3. Studying Agent Interfaces "In the wild"

Recent developments in the consumer electronics industry will now allow for an easier deployment of integrated automation technologies with various input and output modalities, such as speech, projection or gestures. There are also very recent efforts by startups to create "smart life assistants" such as Emotech (*Emotech | Olly*, 2015) which uses artificial intelligence and creates the system's demonstrated personality based on the user's, or cubic (*Cubic*, 2015) which offers to control building technologies in a conversational manner. Similar to how the increasing adoption of home automation technologies allowed us to study them "in the wild," soon, researchers will be able to study personified agent interfaces embedded into the domestic context. We believe that addressing the following questions in future work will be of value to not only the smart home research community but for human-computer interaction in general, to inform future experiences with increasingly "smart" computing technologies.

How do personified agents perform in everyday usage?

Our explorations in the space of interface agents and the agency of smart homes were limited to laboratory studies. They provided valuable insights about the general attitude of people, but perception might change significantly when interacting with such an interface daily and when it is embedded into a home. Brush et al. (Bernheim Brush, Johns, Inkpen, & Meyers, 2011a) conducted a preliminary study to learn about the potential of speech interactions in the home in terms of interest in different kinds of information, the data currently collected by companies such as Amazon via their Echo/Alexa or Apple via Siri, would allow researchers to learn about other interests such as the control of devices. Besides that, such data might offer insights about how people interact with the personalities demonstrated in their systems.

How does the multi-user context affect the users' perceptions usefulness?

From our empirical work, we learned that smart home user experiences can differ significantly across the users in the same household. We also learned that children and parents had different perceptions of the concept of emoting objects in the home. Besides those personal differences in the experience, the practicality for finding reliable technical solutions in a multi-user scenario is an open topic.

How does the preference for various personalities or the extent of the use of emotions vary by space and area of application?

While we focused exclusively on the domestic context, the application of agent interfaces and affective computing could potentially be useful in many more fields. Currently, there are increasing efforts to push autonomous driving which opens similar challenges for the intelligibility of automation, trust, and comfort.

7.3. Closing Remarks

This dissertation has laid out the broad landscape and the design space for current and potential future smart home user experiences from the perspectives of research, industry, smart home inhabitants and people with interest in this topic. The presented work adds to this rich existing knowledge of how people live with new technologies and how they use them in the domestic context. The presented notion of the roles, cycles of adoption of smart homes, and the understanding of the challenges for each, can guide researchers and designers to contribute further to this growing knowledge of people's interactions with automation technologies.

We created multiple prototypes to probe into the design space of future smart home interactions. While we explored these three approaches (routines, personality, and emotions) individually, we believe that future smart homes will unite aspects of all of them. For example, the calendar metaphor is helpful for inhabitants to understand the events that are happening in their homes and their patterns over time. This allows them to learn specifics about their home and how it could be adjusted to meet their lives better. The personality approach abstracts from this granularity, which could potentially help users to get started with "smart" functionalities in their home, simplifying the overwhelming amount of possibilities for configuring their home, while allowing the user to engage in conversations. Expressions of emotions are even more abstract and thus cannot be used to convey specific information beyond cues. However, as they are embedded in the individual devices they could convey the inhabitants with "senses," e.g. a sense of danger, urgency or relief regarding a specific object of interest. These three approaches to learning about interactions should be considered an addition to the toolbox of designers. We believe that well-designed smart home user experiences will allow the various user roles in homes to transition seamlessly between them, not only as their skills might change over time but also simply to match their preference at any given point in time.

Due to the rapidly changing area of smart homes, connected homes, and the Internet of Things, the interaction modalities of our design probes into the future realm of smart home user experiences will soon be outdated. However, they have revealed human attitudes towards systems that progress from acting automatically, based on the intelligence that users program into them, to systems that create their own reasoning and ways to express themselves, based on what they sense of the environments, which will remain of relevance for decades to come.

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Appendices

Appendix A. **Multiple Stakeholders Study**

A.1 Consent Form Professionals

University of Zurich[UZH]

People and Computing Lab

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Informed Consent "ZPAC Building Technologies Study"

Dear participant,

we are investigating the integration of smart technologies in domestic homes and we would like to invite you to participate in our study, which will help us learn more about the needs of inhabitants of technology-equipped homes.

What will we ask you to do?
If you agree to participate in this study, you will be interviewed for approximately one hour about your company's product portfolio, what these products aim to achieve, and your future vision of life with building technologies. Further, we would like to gain insight into your experiences with clients: what motivated them to integrate "intelligent" technologies into their private domestic homes, as well as the effect of these technologies on the everyday lives of inhabitants.

What type of personal information will be collected?
The interview will be recorded (audio) and may be partially- or fully-transcribed. You will remain anonymous in any written publication or presentation based on this research. If we choose to use some of your comments, they will be attributed to a participant number or a pseudonym.

Are there risks or benefits when participating?
There is no cost to participate in this study and there are no particular risks associated with the study beyond those associated with normal everyday activity.
You will receive no compensation for your participation, but we will send you copies of any resulting publications. If you like, we are happy to include you in our international publication. In case you would like to be mentioned in the acknowledgments section, please let us know under what terms we may include your name or your company's name.

What happens to the interview data?
Participation in the study is voluntary and confidential. You are free to withdraw your participation at any point during the study, without needing to provide any reasons. Any information you contribute up to the point at which you choose to withdraw will be retained and used in the study, unless you request otherwise.
Your data (audio files and/or interview transcripts) will be saved on password-protected devices or in locked university filing cabinets or rooms of the University of Zurich. They will be stored for five years, after which they will be permanently deleted.

Uses of the interview data
The results of this study will potentially appear in both internal and external presentations and publications, as well as academic journals and conference proceedings.

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Consent

If the interview is conducted via phone or Skype, we will ask you to give your oral consent during the audio recording.

With your signature on this form you confirm the following statements:

- An investigator explained the study and the listed conditions to me. I had the opportunity to ask questions. I understood the answers and accept them
- I am at least 18 years old.
- I had enough time to make the decision to participate and I agree to the participation.

In no way does this waive your legal rights or release the investigators or involved institutions from their legal or professional responsibilities. You are free to withdraw from this research project at any time. You should feel free to ask for clarification or new information at any time during your participation.

____

Participant's name (please use bold letters)

____________________ ____________________

Location, Date | Participant's signature

____

Researcher's name (please use bold letters)

____________________ ____________________

Location, Date | Researcher's signature

If you have further questions regarding our research and/or your participation in this study, please contact:

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A.2 Interview Protocol Professionals

Interviewleitfaden für Unternehmen
1) Begrüßung und Einleitung
Wie geht es Ihnen? Vielen Dank, dass Sie sich die Zeit für das Interview nehmen!
Ganz kurz etwas zu mir:
Doktorandin und Forschungsassistentin bei Prof. Elaine Huang in der HCI Gruppe ZPAC an der Uni Zürich.
Hintergrund Informatik und Architektur

Ist es okay, wenn ich die Aufnahme bereits starte?
Haben Sie sich die Information und Einverständniserklärung durchlesen können?
Haben Sie noch irgendwelche Fragen?
Stimmen Sie den Teilnahmebedingungen zu?
Vielen Dank!

Wie bereits in der Teilnahmeinformation beschrieben, würde ich gerne mehr über [Firma] erfahren, was Sie mit Ihrem Angebot gerne bewirken möchten und was Ihre Vision des zukünftigen Wohnens mit Gebäudetechnologien ist.
Des Weiteren befassen wir uns mit der Motivation Ihrer Kunden sich "intelligente" Technologie für den Privathaushalt anzuschaffen, sowie mit den Einflüssen, die diese Technik auf das Alltagsleben der Bewohner hat.
Also, wie Sie merken geht es mir hauptsächlich um Ihre Privatkunden bzw. Kunden die Technologie in ihre Privaträume installieren lassen.

2) Was ist das für eine Firma? Ermöglicht Vergleiche zwischen den verschiedenen Interviewpartnern
Laut Website gibt es [Firma] seit [19xx], ist das korrekt? Seit wann sind Sie dabei?
Wie würden Sie Ihr Produktportfolio beschreiben?

3) Definition von den Begrifflichkeiten „Smart Home", „Intelligentes Gebäude", wo sehen die Anbieter eine Grenze zur normalen Gebäudetechnik?
Es wird ja gern der Begriff Smart Home oder Intelligente Gebäude verwendet: was bedeutet für Sie dieser Begriff. Gehört ein Lichtschalter dazu? Oder ein Bewegungsmelder?
Nach Sensoren nachfragen

4) Woher beziehen die Firmen ihre Inspiration und entscheiden, was auf den Markt kommen soll? Wie viel Feedback erhält die Firma vom Endkunden?
Sie hatten erwähnt, dass Ihre Firma in den letzten Jahren mehr und mehr expandiert.
Was für neue Produkte wurden aufgenommen bzw. selber Produkte entwickelt?
Planen Sie schon an weiteren über die Sie reden können?
Woher kam der Antrieb gerade diese Produkte zu entwickeln?
Welche Produkte/Dienstleistungen fragt dieser Kunde besonders häufig an?

5) Typischer Ablauf eines Projektes, wie nah am Kunden wird gearbeitet?
Um eine konkrete Vorstellung von den Abläufen bei Ihnen zu bekommen: kannst du mir einfach von einem in der letzten Zeit realisierten Projekt für eine Privatperson erzählen? Welche Produkte haben Sie dort installiert?
Frage nach „Apps"
Fokus auf die formulierten Wünsche der Kunden

Kontakt-/Beratungs-/Planungsphase
Wie ist die Person auf Sie gekommen?
Mit welchen Vorstellungen kam die Person zu Ihnen? Wie formuliert er seine Wünsche?
Sagt der Kunde, aus welchem Grund oder welchem Zweck er diese will?
Welche Vorkenntnisse hatte der Kunde schon?

Über welchen Zeitraum lässt er sich beraten bis es tatsächlich zur Installation kommt und wie oft sprichst du mit dem Kunden?

Installationsphase

Gab es schon mal Kunden, die sich an der Installation der Hardware beteiligt haben? Ist das häufiger so?
Beteiligen sich Kunden an der Konfiguration der Produkte? Was zählt dabei zur Konfiguration?
(Sind die Kunden stets Neulinge? Gibt es „hausgemachte Technologien"?)
In was für Räumlichkeiten installiert ihr die Sachen meistens? Neubau, Altbau, Wohnung, Haus, Villen?
Hatten einige Kunden schon Gebäudetechnologien installiert? Vielleicht etwas Selbstgebautes/-entwickeltes? Wofür diente das?
Was habt ihr dann geändert? Neues System installiert oder etwas drauf gesetzt?
Hat eure Technologie deren Technologie ersetzt mit der gleichen Funktionalität oder etwas ergänzt oder verbessert?

Wartungsphase

Stehen Sie jetzt nach Abschluss noch in Kontakt mit der Person? Ist das immer so?
Ist das ein typischer Ablauf eines Projekts bei euch?

6) Gibt es einen Stereotyp von Kunden? Gibt es eine typische Motivation zum Kauf von „Smart Home"-Technologien?
War das ein typischer Privatkunde? Haben Sie einen typischen Kunden? Was zeichnet diesen typischen Kunden aus?
Hat sich am Kundenprofil über die letzten Jahre etwas geändert?

8) Welchen Einfluss hat die Technologie auf den Kunden im Alltag?
Ihr bietet ja auch technischen Support an: kannst du dich vielleicht an einen Fall in der letzten Zeit erinnern? Was hat eurer Kunde an Support angefragt?
Kommen eure Kunden manchmal auch so zurück und erzählen, was für Erfahrungen sie mit den Produkten machen?
Kannst du dich an irgendeinen besonders zufriedenen Kunden erinnern? Was gefiel ihm besonders?
Sind auch schon mal Probleme vorgekommen, irgendetwas, womit der Kunde unzufrieden war?
Gab es ein Projekt, bei dem ihr nachbessern musstet, damit ihr und der Kunde zufrieden wart?

9) Wie sollte die Technologie im Idealfall wirken?
Wie anfangs gesagt, uns interessiert auch was ihr mit euren Produkten bewirken wollt. Neben dem Geld verdienen natürlich ;)
Was ist z.B. ein gelungener Abschluss eines Projektes? Wann sind eure Erwartungen an euch erfüllt?
Inwiefern würdest du sagen verändert eure Technologie das Alltagsleben der Bewohner? Wird sich in den nächsten Jahren etwas daran ändern?
Ihr arbeitet ja auch mit Forschungseinrichtungen zusammen? Inwiefern beeinflusst das eure Produkte?
Wie sieht in deiner Vorstellung ein Tag in dem "Haus der Zukunft" in 20 Jahren aus?

A.3 Consent Form Planners/Inhabitants

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Informed Consent "ZPAC Living in Smart Homes Study"

Dear participant,

we are investigating the integration of smart technologies in domestic homes and we would like to invite you to participate in our study, which will help us learn more about the needs of inhabitants of technology-equipped homes and to inform future design of such.

What will we ask you to do?
If you agree to participate in this study, you will be interviewed for either approx. 45 to 60 minutes on phone or approx. 75 to 90 minutes in person in your household about the topics home automation and "living in intelligent buildings". If your currently planning your new home, we will have a focus on your current experiences and your motivation to make your new home "smart". If you already live in your new home, we are further interested in your experiences of using the various installed technologies

What type of personal information will be collected?
The interview will be recorded (audio) and may be partially- or fully-transcribed. With your consent we will take photos for a better understanding and for illustrating the audio recording. You will remain anonymous in any written publication or presentation based on this research. If we choose to use some of your comments, they will be attributed to a participant number or a pseudonym. Please sign with your initials next to the usage options you agree with

- ___ I allow audio recording of the interview under the condition of remaining anonymous in any public use.
- ___ I allow taking under the condition of remaining anonymous in any public use.

Are there risks or benefits when participating?
There is no cost to participate in this study and there are no particular risks associated with the study beyond those associated with normal everyday activity. We would like to thank you for your time with either an Amazon- or ExLibris-Voucher in the amount of CHF 25 (€23) for the longer interview in your home, and in amount of CHF 15 (€14) in case we interview you for up to an hour. In case you are further interested in our research, we will happily let you know about our future publications.

What happens to the interview data?
Participation in the study is voluntary and confidential. You are free to withdraw your participation at any point during the study, without needing to provide any reasons. Any information you contribute up to the point at which you choose to withdraw will be retained and used in the study, unless you request otherwise.Your data (audio files and/or interview transcripts) will be saved on password-protected devices or in locked university filing cabinets or rooms of the University of Zurich. They will be stored for five years, after which they will be permanently deleted.
The data can be used and seen by resesarchers directly involved in this project. With your explicit consent you can allow further people access to the data for educational purposes or the application of further scientific methods. Please sign with your initials next to the usage options you agree with.

- __ I allow the use of my anonymized data for educational purposes within the scope of classes offered by ZPAC for bachelor-/master students.
- __ I allow the use of my anonymized data by external researchers to apply scientific methods.

Uses of the interview data
The results of this study will potentially appear in both internal and external presentations and publications, as well as academic journals and conference proceedings.

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People and Computing Lab

Universität Zürich
People and Computing Lab
Binzmühlestr. 14
CH-8050 Zürich

Ansprechpartner:
Sarah Mennicken
Telefon +41 44 63 56727
Mobil +41 789 223303
mennicken@ifi.uzh.ch

Consent

If the interview is conducted via phone or Skype, we will ask you to give your oral consent during the audio recording.

With your signature on this form you confirm the following statements:

- An investigator explained the study and the listed conditions to me. I had the opportunity to ask questions. I understood the answers and accept them
- I am at least 18 years old.
- I had enough time to make the decision to participate and I agree to the participation.

In no way does this waive your legal rights or release the investigators or involved institutions from their legal or professional responsibilities. You are free to withdraw from this research project at any time. You should feel free to ask for clarification or new information at any time during your participation.

____
Participant's name (please use bold letters)

____________________ ____________________
Location, Date Participant's signature

____
Researcher's name (please use bold letters)

____________________ ____________________
Location, Date Researcher's signature

If you have further questions regarding our research and/or your participation in this study, please contact:

Dipl.-Inform. Sarah Mennicken

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People and Computing Lab
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CH-8050 Zürich

A.4 Interview Protocol Planners

"Living in Smart Homes" Research Protocol

Name:
Ref. Number:
Date/Time:
☐ Consent Form
☐ Incentive
☐ Receipt

To have at hand:

- Study Information and Consent Forms
- This protocol + pen + paper

General procedure:

- Herzlichen **Dank**, dass Sie an meiner Studie teilnehmen.
- Wie bereits erwähnt geht es in dieser Studie um **Ihre Erfahrungen mit "smarten Dingen"** in Ihrem Zuhause. Was mir noch wichtig ware, im Vorhinein zu betonen ist, dass es **keine richtigen oder falschen Antworten** auf meine Fragen gibt, es zählt ganz allein **Ihre Erfahrung und Wahrnehmung**. Ich will natürlich soviel wie möglich von Ihnen erfahren und daher sicherlich häufiger bei Dingen nachfragen, aber bitte lassen Sie es mich einfach wissen, wenn Sie nicht wohl fühlen **gewisse Informationen mit mir zu teilen**. Das ist vollkommen in Ordnung!
- Go over consent form
- Start recording, ask for consent on tape
- Conduct interview
- Stop recording
- Explain how incentive is processed
- Thank participant

A. Warm up and Background information on participant

a. *Learn about the participant's background and what they consider most important of their home, the "smartness" of their home.*

- **Can you tell me a little bit about your current living situation??**
  . [Age, job, roommate/partner/family]

  . Do you already have any function of smart home functionality in your current home?

B. Explore the general appeal of home automation

a. *(research = informing yourself about the options)*

b. *Why did they get the infrastructure in the first place? How did it influence the general planning of their new home? Did it involve architectural changes or adjustments? Did it influence the way they layout their rooms? What categories exist? Pure functions vs. stuff like ambient mood luminance*

- **When and how did you start to become interested in smart home technology?**

- **Are you looking for concrete options? Since when?**
  . [Did you already do research on places or properties?]
  . [Is the home planned for you? Are you involved in the planning process?]]

. **How does the home automation influence the planning?**

c. *Who is the main contributor and "booster" to get it? How were others involved? What are their expectations?*

- **What functionalities do you and [people you're living with] want?**

- [Do you have the same requirements?]
- How's doing the research and compares the options?
  [Who's taking the final decision?]
- What people did you consult?
  . [[Partner, Kinder, Familie, Freunde, Kollegen]]
- **What are you discussing or maybe even argue about?** Pro/Contra arguments?

d. *How did they do the research?*

- How did you learn about that system/technology?
  . [[Consulted by company? Which one?]]
- Where do you look for information?
- Who/What is helping you with that?
  . [[experts (e.g. in forums) vs. websites vs. company/consultant]]
- **Are the available systems sufficient to cover your needs?** Is there something that you wanted but couldn't get? [[form factor, appearance, color, functionality, features, price,..]]

C. Identify the understanding of the concepts "smart" and "home"

a. *Where is the boundary between people's understanding of "smart", "intelligent" and just automated? Get an overview about what people actually have, learning about the variety of devices/services and how it changed the architecture/interior design*

- **Besides home automation, do you already have some "smart things" in your home? Maybe something that's not technical?**

- **What do you appreciate/like about them most?**

  . [What do you use most often? What do you consider most helpful?

"Living in Smart Homes" Research Protocol

b. *Definition of "Home Qualities" and how they are influenced by home automation, What are important characteristics of their home? Where is it influenced (improved, inhibited, decreased) by technology?*

- **What activities in your home do you like doing?**
  . [remind them of what's included in their home (e.g. garden, garage, basement, ..)]
  . [[in which room, area do they happen, why?]]
  . [[doing it together with someone or rather alone]]
  . How do those smart things help you or support those activities??
  .
- **Which activities at home do you like less?**
  .
  . How do your smart things help to get them done?
  .

C. Effects on Home Quality

c. *How are the different devices connected? Learn about context and importance of home automation by asking for other technologies' usage patterns. How do people interact with their homes?*

- **What electronic devices or technologies are important in your everyday life?**
  . [write down as a list to use in later questions]
  .
- **Does that device come into play regarding the installation of home automation?**
- Gibt es andere Dinge, die mit Ihrem Haus kommunizieren?

d. *Learning about secondary users: how do they take advantage of the technology? What would they like?*

- [[if secondary users are rather negative: which technologies do they like?]]
  . [[why these?]]

D. Wrap up

a. *How did their routines change in the new home? (not especially aimed at interacting with technology), Is home automation providing the assistance they expected?, Do participants save time with that technology?*

- **What differences did you perceive between your old home and the home you're living in right now?**
- **Did you recently spent some time somewhere else (friend's place, vacation,..)? What did you miss about your home?**

A.5 Interview Protocol Inhabitants

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"Living in Smart Homes" <u>Home Tour</u> Protocol

To bring:
- Study Information and Consent Forms (2x per participant)
- Participant incentives and incentive forms
- Audio recorder + phone backup (backup batteries and check space on memory card)
- Digital camera (check battery)
- This protocol + pen + paper
- Business cards

General procedure:
- Thank participant, introduce yourself, study, and research purpose
- Herzlichen Dank, dass Sie an meiner Studie teilnehmen.
- Wie bereits erwähnt geht es in dieser Studie um Ihre Erfahrungen mit "smarten Dingen" in Ihrem Zuhause. Was mir noch wichtig ware, im Vorhinein zu betonen ist, dass es keine richtigen oder falschen Antworten auf meine Fragen gibt, es zählt ganz allein Ihre Erfahrung und Wahrnehmung. Ich will natürlich soviel wie möglich von Ihnen erfahren und daher sicherlich häufiger bei Dingen nachfragen, aber bitte lassen Sie es mich einfach wissen, wenn Sie nicht wohl fühlen gewisse Informationen mit mir zu teilen. Das ist vollkommen in Ordnung!
- Go over consent form, leave one copy with the participant, have the other one signed (have wife sign it as well, if suitable)
- Conduct interview and home tour, take pictures as needed
- Give incentive and collect signed incentive form
- Thank participant

Name:
Ref. Number:
Date/Time:
- ☐ Consent Form
- ☐ Incentive
- ☐ Receipt

A. Warm up and Background information on participant

a. *Learn about the participant's background and what they consider most important of their home, the "smartness" of their home.*
- **Can you tell me a little bit about your current living situation?**
  - [Age, job, roommate/partner/family]
- How long have you been living in this house?
  - How long with/without smart home technology?
- What kind of smart home do you live in? **What is unique about your home?**
- Where and how did you live before?
  - [what kind of house/apartment did you live in?]
  - [did they live in a smart home before?]
- What stuff did you get for your new home?
  - [what was your last addition?]
  - [what are you currently planning to install, add?]

B. Explore the general appeal of home automation

a. *(research = informing yourself about the options)*

b. *Why did they get the infrastructure in the first place? How did it influence the general planning of their new home? Did it involve architectural changes or adjustments? Did it influence the way they layout their rooms? What categories exist? Pure functions vs. stuff like ambient mood luminance*
- **When and how did you start to become interested in smart home technology?**
- **When did you decide to start informing yourself about the options on it?**
- Did you do research on it before you started looking for places or ground to build on?
- Did you plan that house yourself?
- When you started planning, did you know which systems you were going to install?
- **How did it affect your planning?**

c. *What categories of "stakeholders" are there?*

"Living in Smart Homes" <u>Home Tour</u> Protocol

- How much participation in the installation process was required for the system you picked?

d. *Who is the main contributor and "booster" to get it? How were others involved? What are their expectations?*

- **What functionalities do you and [people you're living with] want?**
- Who did the research?
  - . [[Who took the final decision?]]
- What people did you consult? Partner, kids, family, friends?
- Did you have the same requirements?
- **What did you discuss about?** What were pro/con arguments?

e. *How did they do the research?*

- How did you know/discover that system/technology?
- Where did you look for information?
- **Were you missing something that you wanted but couldn't get?**
  - . [aesthetics, form, color,...]

f. *Were their expectations met?*

- **Were the available systems sufficient to cover your needs?**
- What would you have done differently if you had to look for it now?
- **Was there something that was more useful than expected?**
- **Was there something that was less useful than expected?**

B. Identify the understanding of the concepts "smart" and "home"

g. *Where is the boundary between people's understanding of "smart", "intelligent" and just automated? Get an overview about what people actually have, learning about the variety of devices/services and how it changed the architecture/interior design*

- **HOME TOUR: Can you show me the "smart things" in your home?**
  - . [room by room + outside]
  - . [[write down as a list to use in later questions, decide what to probe on and highlight those]]
  - . [[where are they?]]
  - . **What makes them smart?**
  - . Example on how they used them [usually → did you do that this morning? When was the last time you did that?]
  - . [[probing on sensors, distinction between motion sensors and others]]
  - . Besides the home automation, are there any other "smart things" in your home?
- **Which one do you like/value most?**
  - . [Which do you use most, Which do you consider most helpful?]

h. *Definition of "Home Qualities" and how they are influenced by home automation, What are important characteristics of their home? Where is it influenced (improved, inhibited, decreased) by technology?*

- **What things do you like doing at home?**
  - . [remind them of what's included in their home (e.g. garden, garage, basement, ..)]
  - . [[doing it together with someone or rather alone]]
- **What do you like/dislike about your home?**
  - . How do the smart things in your home support that activity?
- What is your favorite part/room of your home? Why?
- **What are activities you like less in your home?**
  - . How do the smart things in your home help you with doing the lest favorite activities?

C. Effects on Home Quality

i. *How are the different devices connected? Learn about context and importance of home automation by asking for other technologies' usage patterns. How do people interact with their homes?*

- **What electronic devices or technologies are important in your everyday life?**
  - . [write down as a list to use in later questions]
- **Does that technology get data from the home or communicate with the home?**
- Can you use System X to retrieve information about your home or to control your home?

“Living in Smart Homes” Home Tour Protocol

- Are there any other devices that communicate with your home?
  . Can you give me an example?

j. *Learning about secondary users: how do they take advantage of the technology? What would they like?*
- [[if secondary users are rather negative: what technology do you like/appreciate?]]
  . [[why these?]]
  . [Can you contrast that to the home automation?]
  . [[What would you like to have?]]

k. *Where do people retrieve information (sensor data as well as media data) in their home? What information do they get and use from their home? How do they use it? Where do they need what kind of information from the home?*
- Tell me about System X/Application Y [from the list created earlier]. How does it come into play in your life?
- **What information do you check on the home automation interfaces? What was the last time?**
- **Can you get the same information from somewhere else as well?**
- Does that help you with any decision you take for your day?
  . [[look for a specific instance]]
  . [e.g. weather or traffic status]

l. *How well do they deal with the systems and to what extent do they customize it to fit their purposes? How do they achieve flexibility? How well does a system work that is not customized by the user herself?*
- Do or did you program, configure the system yourself? Did you customize the interface?
- **What did you change? For what reason?**
- Do you change it frequently? What are reasons for that?
  . [[regular things, specific occasions?]]
- What was the last time you configured/customized/modified the system/application/UI?
- **What do you do when you run into problems, when trying to get the system to do something it’s not set up to do yet?**

m. *Do people feel like they’re in control of the technology?*
- **Did your system ever do something cool?** Something memorable, surprising?
- Does that happen a lot? Was it a one-time-thing? Can you tell me about that?
- **Did you ever feel fooled by the system?**
- Does that happen a lot? Was it a one-time-thing? Can you tell me about that?
- **How did you fix it?**
- Did you try to find out why it acted like that?

n. *Who benefits most of that?*
- Who is using it most? Who is modifying it most?

C. Wrap up

a. *How did their routines change in the new home? (not especially aimed at interacting with technology), Is home automation providing the assistance they expected?, Do participants save time with that technology?*
- **What differences did you perceive between your old home and the home you’re living in right now?**
- **Did you recently spent some time somewhere else (friend's place, vacation,..)? What did you miss about your home?**
- And what weren’t you missing at all?

Appendix B. **Passive Users Study**

B.1 Consent Form

University of Zurich[UZH]

People and Computing Lab

Universität Zürich
People and Computing Lab
Binzmühlestr. 14
CH-8050 Zürich

Contact Person:
Sarah Mennicken
Telefon +41 44 63 56727
Mobil +41 789 223303
mennicken@ifi.uzh.ch

Informed Consent "Experiences with my 'Smart Home' "

Dear participant,

We are inviting you to participate in our study on home automation. We conduct this scientific study to gain a better understanding of the needs of inhabitants of homes with building technologies and to contribute to the development of such future technologies.

What will we ask you to do?
If you agree to participate in this study, we will ask you for two things:

1. We would like to ask you to collect your everyday experiences in your "smart home" over the course of two weeks in a written way and send us those comments back before the second part of the interview along with some documenting pictures and a self-drawn sketch of your home's layout. (You will get more detailed instructions on how to collect those comments and a kit with all the necessary materials).
2. Afterwards we would like to interview you for about 60-90 minutes about those experiences.

What type of personal information will be collected?
The interview will be recorded (audio) and may be partially- or fully-transcribed. With your consent either we will take photos or ask you to take photos for a better understanding and for illustrating the audio recording. You will remain anonymous in any written publication or presentation based on this research. If we choose to use some of your comments, they will be attributed to a participant number or a pseudonym. Please sign with your initials next to the usage options you agree with

___ I allow audio recording of the interview under the condition of remaining anonymous in any public use.
___ I allow taking under the condition of remaining anonymous in any public use.

Are there risks or benefits when participating?
There is no cost to participate in this study and there are no particular risks associated with the study beyond those associated with normal everyday activity. We would like to thank you for your time with either an online gift-voucher (the specific website can be agreed upon in the email correspondence) in the amount of $40. In case you are further interested in our research, we will happily let you know about our future publications.

What happens to the interview data?
Participation in the study is voluntary and confidential. You are free to withdraw your participation at any point during the study, without needing to provide any reasons. Any information you contribute up to the point at which you choose to withdraw will be retained and used in the study, unless you request otherwise.Your data (audio files and/or interview transcripts) will be saved on password-protected devices or in locked university filing cabinets or rooms of the University of Zurich. They will be stored for five years, after which they will be permanently deleted.
The data can be used and seen by resesearchers directly involved in this project. With your explicit consent you can allow further people access to the data for educational purposes or the application of further scientific methods. Please sign with your initials next to the usage options you agree with.

__ I allow the use of my anonymized data for educational purposes within the scope of classes offered by ZPAC for bachelor-/master students.
__ I allow the use of my anonymized data by external researchers to apply scientific methods.

Uses of the interview data
The results of this study will potentially appear in both internal and external presentations and publications, as well as academic journals and conference proceedings.

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Ansprechpartner:
Sarah Mennicken
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Mobil +41 789 223303
mennicken@ifi.uzh.ch

Consent
If the interview is conducted via phone or Skype, we will ask you to give your oral consent during the audio recording.

With your signature on this form you confirm the following statements:

- An investigator explained the study and the listed conditions to me. I had the opportunity to ask questions. I understood the answers and accept them
- I am at least 18 years old.
- I had enough time to make the decision to participate and I agree to the participation.

In no way does this waive your legal rights or release the investigators or involved institutions from their legal or professional responsibilities. You are free to withdraw from this research project at any time. You should feel free to ask for clarification or new information at any time during your participation.

____
Participant's name (please use bold letters)

Location, Date | Participant's signature

____
Researcher's name (please use bold letters)

Location, Date | Researcher's signature

If you have further questions regarding our research and/or your participation in this study, please contact:

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Prof. Dr. Elaine M. Huang, Ph.D.

Landline +41 44 635 4411

huang@ifi.uzh.ch

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People and Computing Lab
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CH-8050 Zürich

B.2 Pre-Interview Instructions

Liebe Teilnehmerin,

ganz herzlich bedanke ich mich noch einmal für Ihre Teilnahme an unserer Studie zum Thema "Smart Homes".

Sie halten nun das angekündigte Paket in der Hand, dass folgendes beinhaltet:

- diese Anleitung
- 20 Kommentarzettel
- Stift
- einen frankierten Rückumschlag zum Sammeln und Rücksenden der Kommentare
- Sticker zum Zukleben des Schlitzes im Umschlag

Ich habe Ihnen ja die kleine Aufgabe bereits angekündigt, aber natürlich möchte ich Ihnen noch kurz erklären, um was ich Sie im Genauen bitte. Zur Vorbereitung unseres persönlichen Interviews, würde es mir helfen, wenn Sie und Ihre Familienmitglieder über eine Zeitraum von zwei Woche Ihre Alltagserfahrungen mit der Gebäudeautomation und/oder mit der Steuerung Ihres Zuhauses für mich sammeln könnten.

Um dies möglichst einfach für Sie zu gestalten, habe ich kleine Kommentarzettel vorbereitet, auf denen Sie ein paar Anregungnen finden, wie Ihre Kommentare starten könnten. Es gibt keine guten oder schlechten Kommentare, es geht einfach nur darum, ein besseres dafür zu bekommen, wie Ihr Alltag mit ihrem "Smart Home" aussieht.

Als kleines Beispiel, so könnten Kommentare aussehen:


Kommentar von Sarah am 25.4. 2012 um 14.30 Uhr

☐ Ich wünschte mir... ☐ Es stört mich... ☒ Ich verstehe nicht...
☐ Es ist toll... ☐ Es ist lustig... ☐ Ich habe Sorge...
☐ Allgemeiner Kommentar

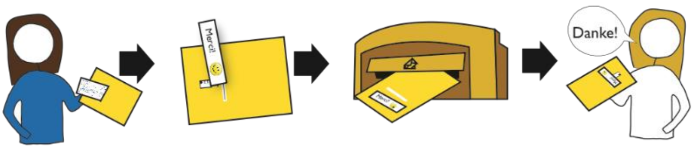
warum die Jalousien im Büro gerade runtergefahren wurden. Vielleicht liegt es am starken Wind?


Kommentar von Sarah am 23.4. 2012 um 8 Uhr

☒ Ich wünschte mir... ☐ Es stört mich... ☐ Ich verstehe nicht...
☐ Es ist toll... ☐ Es ist lustig... ☐ Ich habe Sorge...
☐ Allgemeiner Kommentar

Das meine Wohnung merken würde wenn ich aufstehe und mich mit Kaffee begrüssen würde

Nach zwei Wochen, möchte ich Sie bitten den Umschlag mit dem beigelegten Sticker zu verschliessen und den Umschlag einfach in einen Briefkasten zu werden. So wird er bald bei mir sein und ich kann mich auf vut vorbereiten.



Falls Sie irgendwelche Fragen haben sollten, können Sie mich jederzeit auch unter meiner Natel-Nummer 078 922 3303 erreichen.

Herzlichen Dank und ich freue mich auf unser persönliches Gespräch,
Sarah Mennicken

Universität Zürich[UZH]

PAC

B.3 Comment Card Templates

Comment by (name) ____________ **on** _____ **2012** **at** ___ **AM/PM**

- [ ] I'd wish...
- [ ] I'm bothered...
- [ ] I don't understand...
- [ ] It's great...
- [ ] It's funny...
- [ ] I'm afraid...
- [ ] General comment

_ _

_ _

_ _

_ _

_ _

Kommentar von ____________ **am** _____ **2012** **um** ___ **Uhr**

- [ ] Ich wünschte mir, ...
- [ ] Es stört mich, ...
- [ ] Ich verstehe nicht, ...
- [ ] Es ist toll, ...
- [ ] Es ist lustig, ...
- [ ] Ich habe Sorge,...
- [ ] Allgemeiner Kommentar

_ _

_ _

_ _

_ _

_ _

B.4 Interview Protocol

Session Outline

To bring

- Study information and consent forms (2x per participant)
- Participant incentives and incentive forms
- Audio recorder + phone backup (backup batteries and check space on memory card)
- Digital camera (check battery)
- This protocol + pen + paper
- Paper + colored pencils
- "Sketching task"
- Summary of comment cards from pre-task
- Business cards

Introduction

Vielen Dank, dass Sie an unserer Studie teilnehmen! Mit diesen Interviews möchten wir besser verstehen, welche Wünsche und Ansprüche Leute an die Technologien in Ihrem Haus haben und welche Probleme derzeit bestehen, um geeignetere Technik entwickeln zu können. Natürlich möchte ich möglichst viel von Ihnen lernen und daher viele Fragen stellen und viel nachfragen. Falls Ihnen aber irgendeine Frage nicht passt oder Sie diese nur ungern beantworten, können Sie jederzeit die Beantwortung ablehnen, ohne dass ich beleidigt. Alles, was ich von Ihnen lernen darf, hilft mir weiter, aber ich möchte nicht, dass Sie sich unwohl fühlen. Es gibt bei den Fragen auch keine richtigen oder falschen Antworten, es zählt allein Ihre Erfahrung.

- Go over consent form
- Ask if there are further questions
- Announce to start recording
- Start recording
- Conduct interview
- Stop recording
- Explain how incentive is processed
- Thank participant

[ ] Probe on those if not mentioned.
[[ ]] Listen for those things.

Take picture of home and participant if that is ok for them.

A. Warm up and Background information on Participant (5 min)

Just so that I can learn a little about yourself

- Can you briefly tell me a little bit about yourself and your current living situation?
    - [Age, job]
- Technical proficiency
    - What technologies do you use on a daily basis?
        - [At home?]
        - [At job?]
    - How would you describe your expertise?
    - Do you have any technical education?
    - Any experience in building or configuring technologies?
- Living situation, family makeup (spouse, kids, their technical proficiency)
- [Where is the home situated, size]
    - [How long have you been living in this home?]

B. Relationship with their "smart home" (total of 45 min)

Use complaints/wishes/anecdotes in the following section as trigger for discussion that are about real problems.

I would like to learn a little bit more what makes your home special in terms of the automation and intelligent or smart things you have.

Overview about technologies and Mental Model (10 min)

- Can you tell me about what "smart technologies" you have in your home?

Objective: Does their mental model include connections between sensors and actors? Do they rather consider the objects or the actions to be "smart"?

The phrasing of the sketching task needs to be consistent across all participants in order not to bias in which way they shape their sketch (e.g. floor plans, network diagram, actual house, ...)

- EErstellen Sie bitte eine Darstellung, die zum Ausdruck bringt, wie Sie über Ihr Haus denken und was Sie an Ihrem Zuhause "smart" finden. Sie können dabei verschiedene Farben verwenden, um die Darstellung nach Ihren Vorstellungen zu erstellen. Bitte nehmen Sie sich ungefähr fünf bis zehn Minuten Zeit, um diese Aufgabe zu erledigen.

Capture initial state of their drawing.

- Can you explain the sketch to me?
    - [*Probe on connection between sensors and actors*: do you know why this feature works automatically?]

Depending on what they draw, probe on potential origins for their idea

- [That looks very complicated, is this something you've seen before?]

- [That reminds me of an architectural plan, …]
- Can you tell me why you sketched it in that way?

If you feel throughout the interview that you add something or want to modify your drawing, please feel free to do so.

<u>Usage and Experience (10 min)</u>

Probe on the pre-task comments. Compare active ("I used this...") vs. passive experiences ("It dit this...").

- Can you give me an example of how you recently used the smart technology in your home?
    - [If suitable: Can you walk me through how you did that?]
    - [[How do they talk about their home? e.g. "It", "The technology", …]]
    - [Do you use a computer, tablet PC, smart phone to control it?]
        - Can you walk me through how you do that?
        - What do you primarily do with those devices? [[playing games, checking weather/traffic/..., social networking, forums (cooking, handcrafts,...) … cmp. Google's study on usage of tablet devices?]]

- What's your favorite technology in the home? Why?
    - [Probe for an example on how it provided them with a benefit.]

- *"Smart things that my home does":*
    - Can you tell me about a situation when technology really helped you?
    - What does it currently do that you like?
        - [Are there other such things?]
- *"Stupid things your home does":* What does it currently do that you don't like?
    - [What's annoying about technology in your home? Why?]
    - Can you think of something that would improve that?
- Which technology do you consider most useful? Why?
    - [Probe if there might be disagreement between different family members]

<u>Understanding (10 min)</u>

- Out of the mentioned technologies, which do you feel most confident that you understand how to use? Why?
    - Any other?
- Which ones don't you feel comfortable with your understanding of? Why?
    - Any other?

- Was there ever a situation in which you did not know what your home was doing and why?

- How do you know if the home does what it should do?

    - [Are there situation where this doesn't work?]
    - [[What makes you trust that your home is behaving the way you want it to (or what would make you trust it)?]]

<u>Information Needs (10 min)</u>

Try to get info about what information they want from their home, about their own behavior and what they capture ("quantified self") and what does the home capture. What should be tracked automatically? What kind of connections could we start with in the "calendar UI"?

- Do you remember a time when you wanted more information than the home currently provides? What information was that?
    - What information would you be helpful to get when you're home?
    - What information would be nice to have when you're home?
    - [What information would you like to get about your home when you're at home?]
    - What information about it when you're somewhere else?
    - How would you want your house to communicate information to you?
        - [[Visual, audio, …]]
        - [[Should it be anthropomorphic?]]

<u>Responsibility/Ownership (10 min)</u>

- Can you tell me about a situation when technology really messed up?
    - What caused this?
    - What did you do when it messed up?
    - How did you try to fix it?
        - [[Would they like to fix it themselves? Would they want their partners to have more time to fix it or to consider that more urgent? Would taking more action with home tech take away hobbies from the husband?]]

- Did you ever have an idea on what to change, what to add, what to improve, what to get rid of?
    - Did you or someone else do that?
    - How?
- When you were planning your home? Was there something that you were keen on getting? Why?
- What technology in the home is "yours"?
    - [Why is that yours? What's not yours?]
    - [Is the smart home tech for you (or someone else) ?]

<u>Long term effects on everyday life (5 min)</u>

- How does this home compare to homes you lived in before?
    - [What's better about it?]
    - [What's worse?]
- Did you have to do any changes before it worked for you?

- [[probing on earlier mentioned changes]]

C. Dreaming the perfect "smart home" (total of 15 min)

[Anind's comment] What kind of relationship do passive users want with their home (tool like a hammer, appliance like a refrigerator, information repository like a calendar/Web, a sensing/active character)?

Relationship

Let's get to a more imaginative question or task. Imagine your perfect smart home!

- Describe it
  - What does it do?
    - [Are there other things that you would like your home to do for you?]
    - How does it know what to do?
  - What does it understand about you?
    - How would you want it to know that?
- [[If they describe a dialogue-/command-based interaction]]
  - Tell your house what you want it to change about itself.
  - [Would you like to communicate that verbally? Or is there any other way that you'd prefer communicating with your home?]
- [[If they describe another kind of interaction]]
  - In case it's wrong and doesn't understand you. How would you want to correct it?
  - How should the home compensate for it?

Other topics (if there is more time left)

How do the kids' interaction with the home differ from their own interaction?
Other technologies they enjoy using...
Did they share their experiences in some way? Online?

WRAP UP

Thank you so much for your time and effort! That was really helpful for our research.
But before we stop this interview...do you have anything else that you would like to tell me? Do you have any questions yourself?

Thanks again!

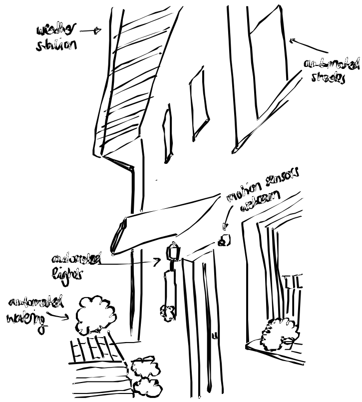
Stop recording
Collect drawing and consent form

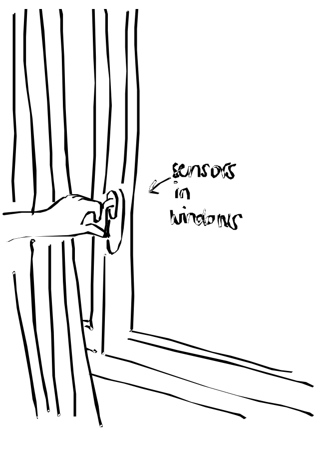
Afterwards: take 5 minutes to debrief.

Appendix C. **Family Personas**

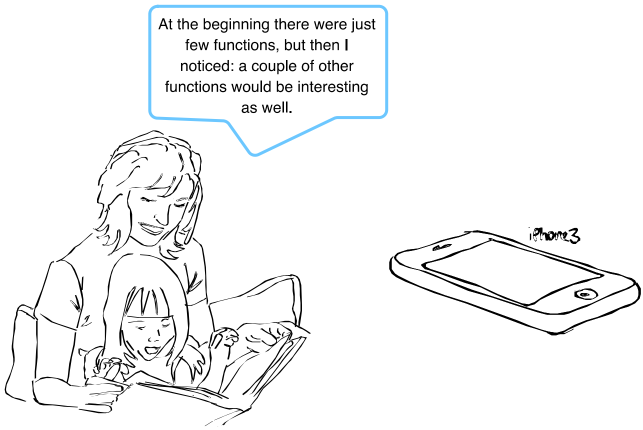
C.1 The Rizzo Home

Peter picked a central server solution for the "intelligence" of their home. Simply because it's easier to maintain for him and it was way cheaper than the distributed bus-system solution. They started out by having shades and light automated based on motion and brightness sensors as well as timers. Later on they added sensors in the windows and a weather station.





Caroline Rizzo, 37



Caroline is a stay at home mum to her two kids: Carla, 2 and Stella, 6. Together with her husband Peter they're all living in a semidetached house in a suburban area since 7 years.

Caroline used to work as a physician's assistant before the kids were born. Now she's dedicating her time completely to the household and the kids. Most of the times she's enjoying that she can stay at home and spent time with them.

She enjoys being very active, so she's doing a variety of sports. On Tuesdays and Thursdays, she goes to the gym when Stella is at the school. Luckily they offer a "kids club" where Carla can play with other kids while her mum is doing Zumba. On the other days she tries to bike to the grocery shop or goes running either with Carla in a stroller or when her husband comes back home and can watch her.

Cooking is one of her hobbies, but in everyday life she actually has to handle it in a more practical way and preparing something quick, but still healthy - especially for the kids. To relax she enjoys watching a movie in the evening after she and her husband brought the kids to bed. At the moment they don't go out very often, but rather just enjoys when she has some time for herself and watch stupid TV shows.

Generally, Caroline likes the automation and is very curious about what her husband is creating to support their lives. But since she had some bad experiences, she is afraid of losing control of very basic features like turning the light on or off or opening the shades or be restricted by a machine. She considers the touch panel and the remote controls as an object for use, so she's not worried that she will break it physically, but afraid she might mess up the settings that took her husband so long to configure.

It's exciting to her when her husband tells her about all the stuff that you can do with automation, but actually, it conflicts a little with her appreciation for doing things herself and is also worried of losing the sense of accomplishment when everything is performed by machines.

Caroline doesn't have any technical training. She's from the generation that learned touch typing and a little bit of Word processing in her apprenticeship but that's all. Because she enjoys to stay in touch with her friends that don't live nearby she started using emails because their faster and more convenient than writing letters. She feels that she can get around with her skills but sometimes being a little bit to slow. Whenever she's in a hurry she wishes it would be a little bit easier for her. She would really appreciate if she could be a bit faster in those moments.

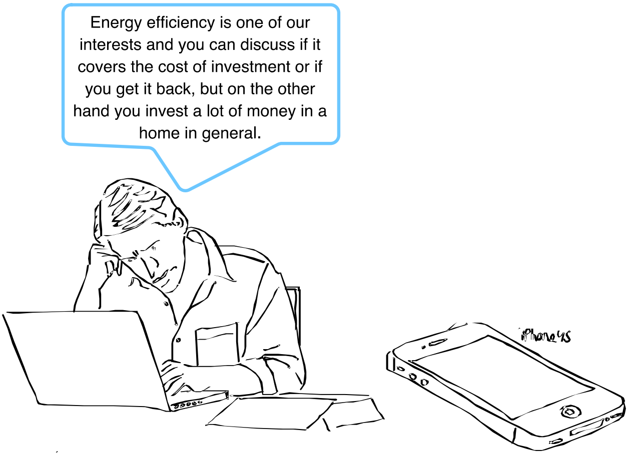
Half a year ago she got an iPhone, it's not the newest version because it's her husband's old phone. There are some apps she really enjoys using: e.g. Whatsapp, because it's almost like the texting she's used to but for free, the local public transit app, because she always forgets the schedule and she recently figured out that you can also see if a train is delayed and also there's a funny local weather app that gives a humorous touch to the weather forecast. Sometimes she's looking up the weather in her favorite vacation spot, not that it provides any real benefit to know that, but it's nice.

The biggest motivation to use the home automation is simply, because it's there and she has to. But also her husband's motivation is contagious sometimes. Caroline is very curious when he's trying new features and it's also exciting when there's new stuff in the home. In order to stay in control of her own home she's very keen on being aware of what he's doing, so at least she's not surprised when the controls in her home change. From time to time she has some ideas of how to change the automation or what would be cool to have and puts it on a paper wish list that Peter has a look at when he gets to it.

While Caroline doesn't have strong technical skills, she knows a lot about the everyday routines and dynamics of her household. She's the one who doesn't only have all the events and reminders in her and the family calendar but also in her head. She's still preferring the paper calendar because it's easier to access and Stella has her own column and starts putting in there when she wants to meet a friend. Her husband has all of his work and private appointments in his digital calendar on his iPhone. He also told her that she can access them on the touch panel but actually she prefers calling him, because usually they need to discuss to coordinate anyways.

Experience Goals	• feel comfortable and safe • feel in control when necessary • be pleasantly surprised • not being bothered
End Goals	• stay in the loop to be aware of problems before they become critical • learn about opportunities for better support • don't waste money/resources/time
Life Goals	• raise the kids responsibly • stay fit and healthy
Definition of smart	Smart is what fits my routines and avoids unnecessary work.
Motivation	Experiencing benefits increases interest in upgrades.
Challenges	Experimenting and testing Tension between comfort and control
We must	• *clearly show what effects will happen and whether conflicts might occur* • *provide a familiar interface to turn to* • *show opportunities for beneficial connections of devices and further automation* • *allow means to provide feedback to the configuring partner*
We must never	• *actuate something without providing means to have access to logs* • *overwhelm with all available information*

Peter Rizzo, 38



Peter is working full time as an consultant in the the finance business. Together with his wife Caroline and his two kids Carla, 2 and Stella, 6 he's living in a semidetached house in a suburban area.

Peter would like to spend more time on his hobbies gardening and photography, but he only has a little time for that on some the weekends or during holiday because in the evening he's often tired and wants to spend the remaining time with his kids. While the home automation "maintenance" is interesting it also became some sort of chore or responsibility for him that he sometimes would rather like to delegate. He also would like to be more active because he's staying seated almost the whole day having to work on the computer. So every once in a while he goes for a very early morning or late evening run.

He's very proud of his home since he and his wife did many things themselves. They're both quite talented when it comes to simple construction tasks. When they were planning to buy the semidetached home almost 7 years ago now they still had a lot of options because it wasn't built yet. Because of a co-worker he learned about home automation and got quickly excited about the potential functionalities it can enable – not so much about the high costs though. As he likes to do things himself plus he thought he could save some money doing the home automation himself he started spending much time online to do research on home automation technologies. He also signed up in an interest group forum and also started going to "real life" meetings with those people some of which he also became friends with and they're now sharing not only mere information about smart homes anymore.

Automating the home became quite a hobby for him, but actually sometimes it bothers him because he would rather have quick solutions for some problems.

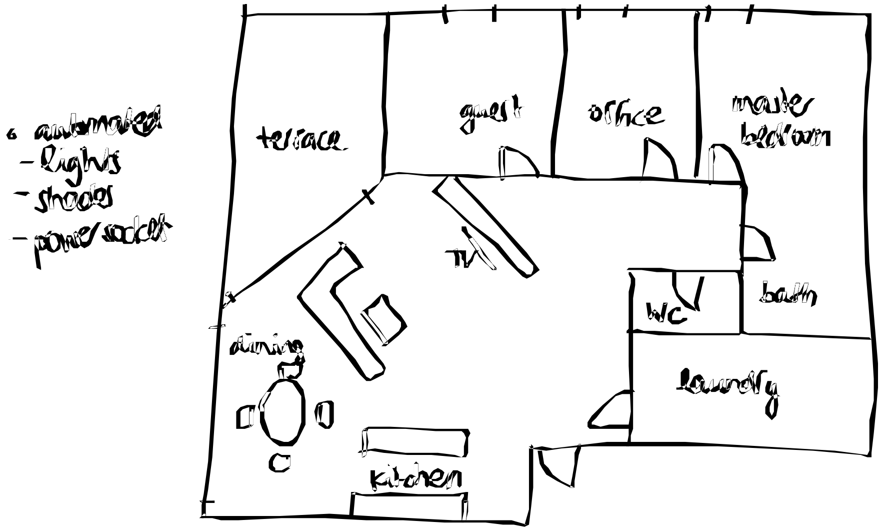
And also finding a "bug" in the home is sometimes really annoying. Because as he's not an electrician he doesn't know whether it's a hardware problem, something in the middle ware or really in his configuration. He spent many hours trying to fix the basement lights only to figure out that it's actually the motion sensor itself that is broken. Whenever his wife tells him an idea for the automation that would fit her everyday routines he's really keen on implementing it but it's difficult to find the time without drawing it from the quality time spending with the family. So often it takes a long time until he can actually make her requests happen.

Although Peter didn't have a professional education in a technical area he's has strong technical skills. Novel technologies have always been a hobby and he started some lightweight programming when trying to set up a website for their wedding 9 years ago. While his background is more in business he has to use a computer, phone and other technical devices also for work, so he feels very confident about these kind of skills. Ever since he became interested in home automation he also started learning more about sensors and is thinking about getting a prototyping kit to experiment with building something himself, although he's quite sure that he won't really find the time for it. He uses the digital calendar on his phone and on his computer because he always wants to have access to it wherever he is.

Peter's motivation to use the home automation was mainly because he got excited from his co-worker's stories and also the stories of his friends from the interest group. Now, he sometimes regrets to have spent money on maybe unnecessary features like the colored LED lights in the wellness area that they're never have the time to use, but he really does like that he can set the light intensity in the hallway based on the day/nighttime. Having a dimmer light in the night is really nice, also if when Stella wanted to sneak into their bed room he didn't have to be afraid that she might fall. In his free time, he enjoys having the entertainment systems connected with a NAS, so that he has access to all the media from almost any interface in the home. And when he cooks something on the weekend he can stream his favorite music to the kitchen.

Experience Goals	• feel comfortable • have fun • stay informed
End Goals	• stay in the loop to be aware of problems before they become critical • be able to try the newest technologies • reduce energy costs
Life Goals	• raise the kids responsibly • life a comfortable life • be successful at work
Definition of smart	It's not smart if I can do it better.
Motivation	Smart homes save energy. Modern homes are smart homes.
Challenges	The challenge of planning for unfamiliar technology. The challenge of getting high-level expert advice.
We must	• *create a unified interface that allows addition of new technologies* • *provide access to the underlying configuration* • *provide options to filter events for easier navigation*
We must never	• *make configuration access to complicated, even if it limits some of the functionalities* • *require to have to doublecheck/verify the interface's functionality*

C.2 The Gardener Home



Frank decided to get a distributed bus-system solution for the flat because he wanted to have all options and also because he wanted to have the best reliability that is available. They have a variety of building technologies automated. The have automated lights based on timers and motion sensors, the shades are connected to brightness sensors and a weather station. The power sockets can be turned off, either individually or via an "all off" function. They further have some gadgets installed, like the cat flap that only allows their cat to come in and the cat food logger, that takes a picture and records the time the cat eats.

Frank Gardener, 43

Frank is a system administrator in a large pharmacy company. He actually used to be an electrician but then made this shift into the administration of IT. Together with his wife Susan he lives in a 4 room apartment in that they bought 2 years ago in one of the calmer neighborhoods of a medium size city.

Technology has always been Frank's hobby. Whenever he has time for it he spends his time researching new technology online, reading the IT paper magazine he subscribed to (and always wanted to change it for an eBook subscription on his iPad), or solders new gadgets in the hobby room in the basement. He simply loves playing around with the newest gadgets and automating the home has become much of a hobby for him. He knows that he should be more active for his health and his wife is trying to motivate him, but it's usually only on the weekend that he goes on a hike with her or a walk in the city.

Frank is very proud of what he installed in his home and he enjoys that he can play around with it – sometimes even playing tricks on his wife or guests by turning lights on or off. He dedicated a lot of time to the planning, but also into the installation. Due to his background of being an electrician he was able to do much of the electrical installation himself, but sometimes he didn't document it that well and thus making it harder to fix problems. When having problems with some sensors or actuators of a specific provider he goes online and posts his problem in an interest group forum. He also contributes and helps other people fix their problems when he can, but he never attended the meetings they organize. He feels like his wife wouldn't approve if he spends even more time on this stuff. He's very keen on giving her ideas a priority when spending time on configuring their home - maybe so she doesn't mind him spending that much time on it.

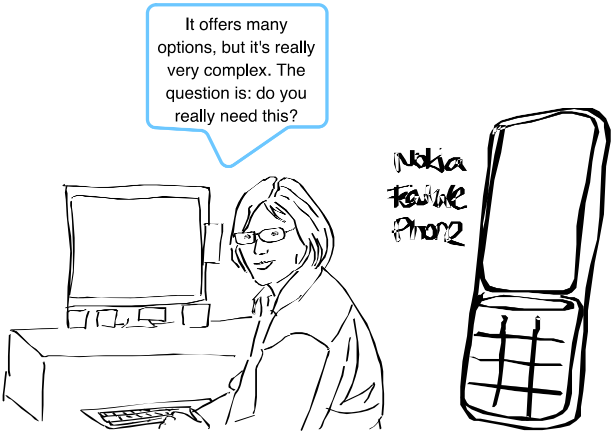
Whatever possible Frank tries to automate, starting with simple motion sensors to control the lights, having the vacuum cleaning robot connected to presence detectors in the home and having a sensor connected to their cat so that he can not only control it's only their cat coming into the apartment but also track at what time the cat eats its food and connected with a photo that's taken with the camera attached to the cat's food bowl. Not useful, but Frank finds it amusing to keep a blog with the sometimes very funny cat pics.

Frank was used to work as an electrician, but actually only for a couple of years, then he transitioned more into the IT sector. He started teaching himself how to program Java and then later C++ and also Python. First by reading books, later mostly with online sources. So, programming the home automation is not really a big deal for him, because it's mostly configuring things (besides the self-made gadgets) but sometimes he wishes that he wouldn't have to used licensed software to be able to do that. Especially, since he feels that this software doesn't have a good usability and doing unnecessary work bothers him a lot. Actually, sometimes he would love to program his own configuration software. Also he considers it to be very frustrating when he's trying to fix a problem, but just can't find the actual cause of it. Is it a bug in his code? Is it the sensor that's causing the problem? Or is one of the wires not properly attached?

Home automation being Frank's hobby is the biggest motivation to automate more and more of the home. He first heard of it almost 20 years ago, but back than it was mostly for office buildings that needed to have central controls. But he was always fascinated by the idea of having advanced means of controls and the resulting comfort in his home. He probably would get rid of all the switches in the home but then he is afraid of upsetting his wife too much who doesn't understand what's the benefit of all that "smart home" stuff.

Experience Goals	• stay informed • be able to make a lot yourself (DIY)
End Goals	• learn about opportunities for new technologies
Life Goals	• life a pleasant life
Definition of smart	It's not smart if I can do it better.
Motivation	Hacking the home as a hobby.
Challenges	Experimenting and testing -> wife
We must	• *clearly log when activities happen and make them actionable* • *provide options to integrate homemade solutions* • *show debugging information*
We must never	• *focus on a pretty interface* • *limit functionality unnecessarily (even if it takes more steps e.g. to have access to the configuration)*

<u>**Susan Gardener, 41**</u>



Susan is a full time employee at an insurance, she's working there for almost 8 years now. Together with her husband Frank she lives in a 4 room apartment in that they bought 2 years ago in one of the calmer neighborhoods of a medium size city.

Susan is a huge fan of being outdoors, that's also why she enjoys her plants on their big size terrace. But she would love to spend more time hiking on the weekends, so she trying to talk her "geek" husband into weekend getaways to the nearby mountains whenever she can. In general, she cannot really understand why her husband enjoys spending that much time in front of a computer. Susan is actually quite happy when she comes back home and doesn't have to sit in front of a machine anymore but can cook, read or meet her friends or talk to them on the phone.

Home automation is a huge hobby for her husband, that's why she's trying to accept that their home is sometimes somewhat a construction site and that there are some unexpected changes in how she has to control the shades or lights. But from time to time she wishes he told her or put up a sign or something, because she at least wants to know what's going on in her own home. At the same time, she also had some ideas on what to automate, like the "iron off" function when the home detects that no one is present. Things like that she really appreciates because they make her feel safe and give her some peace of mind. And as long as she feels that she can control the main things in her home like the shades, lights and the doors it's ok for her when Frank is playing around a little with the home. Often she forgets the ideas she has, but every once in a while she talks to Frank about it in the evenings and he puts down her ideas in his online note taking app. So that he can get back to it whenever he finds time for it.

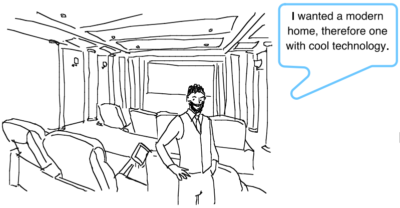
When studying business, she also had to learn how to use some software applications. General ones like the Office Suite and also SAP. She feels confident in using them, but she simply doesn't enjoy sitting in front of a display they whole day. So when her husband showed her how he configures the shades in the home, it wasn't too difficult to understand but she didn't' really see why someone can enjoy doing that like her husband does. Her husband can also control the home via his smart phone and he wanted to get her one as well, but she really doesn't feel the need to do so. When they're on vacation she likes to be able to check whether they turned off everything and whether the presence simulation works but for her it's fine to ask Frank and he can check on it and tell her.

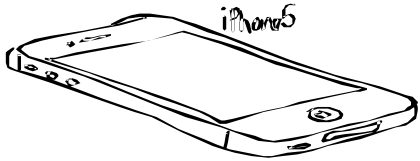
Susan is not extremely motivated to actively configure the home automation simply because she doesn't want to spend her time dealing with more technology than necessary. But from time to time she has some ideas and sometimes she likes to fantasize about a home that makes her her cup of coffee in the morning, but it also feels to her that those things are all luxury wishes and that it might only make her lazy and that's something she doesn't want to be. At the same time, while being entirely unnecessary one of her favorite functions in the home is the automatic turning on/off of the Christmas lights in the winter time. It's simply so welcoming and nice to come back home and see the lights on her way up without having to turn it one first and at the same time knowing that they will turn themselves off later and won't waste more energy in the night when no one can see them.

Experience Goals	• feel comfortable • not being bothered • easy controls
End Goals	• not being restricted in any way
Life Goals	• life a comfortable life • stay healthy
Definition of smart	It's not smart if I can do it better.
Motivation	Experiencing benefits increases interest in upgrades. Smart homes save energy.
Challenges	Automation doesn't re-invent the home; it just makes it more convenient.
We must	• *provide easy means to spot conflicts and create exceptions* • *consider the interface as an optional way to interact with the home* • *clearly show energy- and safety related information*
We must never	• *conflict with the manual access* • *bother with notifications*

C.3 The Miller Home

Mr. Miller, 52





Edward is the CEO of a company which develops software for logistical services. He was pretty lucky in the 90ies with his startup now he's getting quite some money out of it. Almost 10 years ago he bought a villa close to a nice lake with parts of that money but only 3 years ago he did major renovations which included advanced building technologies. Although his girlfriend spends quite some time at his place, especially on the weekends, she still kept her own place.

In theory, Edward has many hobbies, trying new sports, traveling and good whine, but usually he works 24/7 and only rarely takes some time off to actually follow his hobbies. He was always a fan of novel entertainment technologies so when his architect approached him with the idea of hiring a smart home consultant to setup a multimedia entertainment system that's not restricted to one room anymore he easily got excited.

His home is quite fancy and he also wanted it to be somewhat representative because sometimes he invites business partners over and he enjoys showing them the "cool" features of his home. He even had his consultant set up a light scene for the outside lights along the driveway to his home especially for those occasions.

In the beginning those features were still kind of buggy and the configuration was far from optimal, so the smart home consultant was very often at his place to change settings and adjust things. Very often even when Edward wasn't at home. But thanks to the keypad lock at the door he could simply give the consultant his own key code. He's only using his home for leisure activities, he has a cleaning lady who's also taking care of his laundry and some basic grocery shopping. Actually, he doesn't even know how to control the laundry machine.

Edward has a very strong technical background, having started out as a programmer himself. But while he could do the programming of the home to a large part himself, he simply didn't want to deal with it. He just wants it to work and not to bother him. So he's rather delegating all that work to the professionals. Also, he likes that other people do the research for him on what's new so every once in a while the consultant comes with new automation stuff or gadgets that Edward is very eager to have installed.

Experience Goals	• stay informed • feel comfortable and safe • be pleasantly surprised • not being bothered
End Goals	• learn about opportunities for new technologies
Life Goals	• life a pleasant life
Definition of smart	Smart is what fits my routines and avoids unnecessary work.
Motivation	Modern homes are smart homes.
Challenges	Tension between comfort and control
We must	• *clearly show further opportunities to automate* • *provide a very aesthetic interface that is customizable to fit into the general interior design*
We must never	• *don't focus on allowing for configuring the underlying rules* • *don't overwhelm with too much information or notifications*

Appendix D. **Informing Calendaring Study**

D.1 Consent Form

University of Zurich[UZH]

People and Computing Lab

Universität Zürich
People and Computing Lab
Binzmühlestr. 14
CH-8050 Zürich

Contact Person:
Sarah Mennicken
Telefon +41 44 63 56727
Mobil +41 789 223303
mennicken@ifi.uzh.ch

Informed Consent "Calendars and Smart Home Interfaces"

Dear participant,

We are inviting you to participate in our study on calendars and home automation. We conduct this scientific study to gain a better understanding of the needs of inhabitants of homes with building technologies and to contribute to the development of such future technologies.

What will we ask you to do?
If you agree to participate in this study, we will ask you to send us screenshots, photos, or scans of the calendars you are using. (You will get more detailed instructions on how to do this via email). Afterwards we would like to interview you about your calendar usage, as well as to try and comment on our interface prototype. We will give you access to this prototype using a software (Skype/Teamviewer). The whole session will take about 60 minutes.

What type of personal information will be collected?
With your consent the interview (audio) and the screen will be recorded and may be partially- or fully-transcribed. You will remain anonymous in any written publication or presentation based on this research. If we choose to use some of your comments, they will be attributed to a participant number or a pseudonym. Please sign with your initials next to the usage options you agree with

___ I allow audio recording of the interview under the condition of remaining anonymous in any public use.
____I allow screen recording of the interview under the condition of remaining anonymous in any public use.

Are there risks or benefits when participating?
There is no cost to participate in this study and there are no particular risks associated with the study beyond those associated with normal everyday activity. We would like to thank you for your time with either an online gift-voucher (the specific website can be agreed upon in the email correspondence) in the amount of $30. In case you are further interested in our research, we will happily let you know about our future publications.

What happens to the interview data?
Participation in the study is voluntary and confidential. You are free to withdraw your participation at any point during the study, without needing to provide any reasons. Any information you contribute up to the point at which you choose to withdraw will be retained and used in the study, unless you request otherwise. Your data (audio files and/or interview transcripts) will be saved on password-protected devices or in locked university filing cabinets or rooms of the University of Zurich. They will be stored for five years, after which they will be permanently deleted.
The data can be used and seen by researchers directly involved in this project. With your explicit consent you can allow further people access to the data for educational purposes or the application of further scientific methods. Please sign with your initials next to the usage options you agree with.

__ I allow the use of my anonymized data for educational purposes within the scope of classes offered by ZPAC for bachelor-/master students.
__ I allow the use of my anonymized data by external researchers to apply scientific methods.

Uses of the interview data
The results of this study will potentially appear in both internal and external presentations and publications, as well as academic journals and conference proceedings.

Consent
If the interview is conducted via phone or Skype, we will ask you to give your oral consent during the audio recording.

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With your signature on this form you confirm the following statements:

- An investigator explained the study and the listed conditions to me. I had the opportunity to ask questions. I understood the answers and accept them
- I am at least 18 years old.
- I had enough time to make the decision to participate and I agree to the participation.

In no way does this waive your legal rights or release the investigators or involved institutions from their legal or professional responsibilities. You are free to withdraw from this research project at any time. You should feel free to ask for clarification or new information at any time during your participation.

____
Participant's name (please use bold letters)

_____________________ _____________________
Location, Date Participant's signature

____
Researcher's name (please use bold letters)

_____________________ _____________________
Location, Date Researcher's signature

If you have further questions regarding our research and/or your participation in this study, please contact:

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D.2 Interview Protocol

PRE-STUDY TASK

- Have them take two or more screenshots of week/days of Xmas week and the current week using the usually preferred view on it (e.g. with task list open next to it?)
- Have their calendars (and the snapshots) at hand during the interview part of the study
- How do people's calendars look like?
    - Digital/paper
    - Amount of entries
    - Type of entries
        - Todos, reminders
        - Notes
        - Recurring event vs single time events
        - Language used...
    - What meta/context information is there? (How much is context in "the user's head"?)
        - Is mentioned who is participating in the event?
        - Is a location implied or specifically mentioned?
        - Any other annotations? (like "!!" or icons, symbols, …)
    - Where are these entries made?
        - On a specific day?
        - Across several days?
        - Free space somewhere else on the calendar?
- Create List to probe on in interview

(POSSIBLY) TO PREPARE FOR USABILITY STUDY:

- Customize based on participant's name
- Recreate their calendar entries in Casalendar for probing in the last part of the study
- Consent forms
- Incentives
- Pictures of calendars

SESSION WITH PARTICIPANT

1. Introductory Part:
    a. Give brief overview about this session (Pt. 1,2,3), get consent to recording
    b. Start Recording
    c. Get consent on tape
    d. Background Info:
        i. How old?
        ii. Job? Occupation?
        iii. Who's living in your household?

e. Smart Home
    i. Could you list the main functionalities of the home?
    ii. Since when are you living in the smart home?
    iii. How do you like it so far?
        1. What are your favorite things about it?
        2. What are your least favorite things about it?
    iv. Temporal rhythm of their smart home, exceptions? How often do events happen?
        1. What are the different actions that your smart home takes during a typical day? [*If necessary, probe:* Let's say day this week on your calendar?]
        2. Let's take a look at the Christmas week:
            a. Did you do any reprogramming of the smart home behavior for the Christmas week?
            b. Are there things that happened during the Christmas week that were annoying?

f. (HOW DO PEOPLE CAPTURE THEIR ROUTINES?) Identify opportunities for integrating automation technologies into a calendar interface as well as limitations of such an integration? (What can and what can't a smart home know, prepare, do?)

    i. What calendars do you use? Digital? Paper?
    ii. Is it primarily a personal/family/work/… calendar?
    iii. What determines which appointments get noted in the calendar?
    iv. What do you do with reg./routine appointment?
    v. Are there other things that are important to you are not in the calendar? Anything other than appointments?
    vi. Do you note down these things in any other way? [Other calendar-related stuff such as TODO lists, checklists…]
    vii. What's the time window of your to-do lists?
    viii. Do you have any (smart) home-related events or todo in your calendar?
    ix. ["change from summer to winter heating", "new server update", "shampoo" carpets"]
    x. Where do you keep these calendars?
        1. Location, different devices (?)
        2. (Coordination with other people) Do you share them with other people? Do you have access to other family members' calendars?

a. Can/do you modify each other’s calendars?

b. If you were to share your calendar with your family would there be anything in it you wouldn't want to share?

xi. When/how often do you use your calendar?

1. Let's say, when did you check your calendar last?
2. Do you have regular routines on when to look up something or when to add/change events?
3. Do you use notifications?

g. (Connection to SH functionalities?)

i. If we take a look at your calendar entries now, was there anything that you had to change {before/during/after, as a result of} the events that are on your calendars?

ii. Are there any specific events on your calendar that when you see them coming up you know you need to change something about your smart home?

2. Usability Study

a. Provide brief spiel:

i. Casalendar is …

ii. There is no right/wrong …

iii. You can't break the interface …

iv. Explain: Think aloud, let's start with an example (How many windows does your house have?)

b. Is this an interface you're familiar with?

i. (Now line) Do you know what this line means?

1. Yes -> great, in the following scenarios it will indicate the time at which the scenario would take place
2. No -> Explain!

c. This interface shows calendars of different people but also your smart home's calendar.

i. Ask them to take a look and think aloud. (Do they see that there's a smart home calendar? do they think it's a history log? or future actions?

1. What you think the smart home events mean?
2. Anything else you notice?

ii. What do you think could be benefits or downsides of integrating your smart home's actions with the events on your family’s calendar?

d. Start going through the different scenarios

i. Read the task to them if they don't. Tell them about the current time.
ii. Please go ahead and use the interface while thinking aloud and tell me when you think you are done.

e. *REPEAT, THEN* KEEP SCREENSHARING ACTIVE

3. Wrap up
    a. How do you feel about the home being in your family calendar? What do you like/dislike about it?
    b. What did you think of these scenarios? Are they realistic for your home?
    c. Any scenarios can you imagine specifically in your own home? In which situations would you use such this interface?
    d. Are there any events you'd like to schedule for your home? Things that you wish your smart home could do for you at specific times?
    e. Miss anything? Additional thoughts? Any questions?
    f. Thanks! Incentive procedure

Appendix E. Casalendar "In the wild" Study

E.1 Consent Form for Parents

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Teilnehmer-Information und Einverständniserklärung zum Feldtest des Prototypen „Casalendar" von ZPAC

Sehr geehrte/r Studienteilnehmer/in,
wir danken uns für Ihr Interesse an unserer wissenschaftlichen Studie mit dem Zweck den Prototypen „Casalendar" zu testen und das Thema „Kalender und Smart Home Interfaces" weiter zu erforschen.

Um was werden wir Sie bitten?
Wenn Sie der Teilnahme zustimmen, werden wir in Zusammenarbeit mit Ihnen den Prototypen „Casalendar" auf Ihren Haushalt anpassen und Ihn, nach vorheriger Absprache, bei Ihnen installieren. Der Prototyp wird für ca. 4 Wochen bei Ihnen laufen gelassen. In diesem Zeitraum werden wir Sie bitten (und durch wöchentliche Emailnachrichten daran erinnern) mit dem Prototypen zu interagieren und dabei Feedback aufzuzeichnen. Wir möchten Sie bitten sich dazu ca. 3mal pro Woche 10-15 Minuten Zeit zunehmen. Bei der Installation werden wir Sie bitten einen Fragebogen auszufüllen. Am Ende der Studie werden wir Sie bitten zwei Fragebögen auszufüllen, sowie ein kurzes Interview zu Ihren Erfahrungen führen.

Welche persönlichen Daten werden aufgenommen?
Ihre Antworten in den Fragebögen werden anonym mit einer Nutzerkennung gespeichert. Mit Ihrer jeweils expliziten mündlichen Zustimmung werden bei der Installation und dem Ende der Studie Audioaufnahmen der Gespräche aufgenommen. Während der Studienlaufzeit werden Audioaufnahmen/Screenshots nur durch Sie selbst gestartet und dies auch nur während der aktiven Nutzung des Prototypen. Die Audioaufnahmen werden im Anschluss teilweise oder vollständig transkribiert. Bei jeglichen Publikationen und Präsentationen basierend auf dieser Forschung werden Sie anonym bleiben. Eventuell verwendete Auszüge aus den Interviews werden ausschliesslich durch eine Teilnehmernummer oder ein Pseudonym referenziert.

___ Ich stimme den Aufnahmen unter der Bedingung der Anonymisierung bei öffentlicher Verwendung zu.

Gibt es Vorteile, Nachteile oder Risiken an dieser Studie teilzunehmen?
Die Teilnahme an dieser Studie ist für Sie mit keinerlei Kosten verbunden. Für Ihre Zeit möchten wir uns mit CHF 300 bei Ihrer Familie bedanken. Zur Installation des Prototypen werden wir Ihre Unterstützung brauchen um Ihr Netzwerk sowie evtl. auch Ihre Smart Home Konfiguration anzupassen. Forscher und Teilnehmer haben über den potentiellen Funktionsausfall der in der Smart-Home Konfiguration angepassten Funktionen besprochen und sorgfältig bemüht die Risiken des Ausfalls zu minimieren. Während der Installation des Prototypens werden wir, ebenfalls mit Ihrer Unterstützung, Backups erstellen damit Sie nach der Studie den vorherigen Zustand Ihres Hauses (gemeinsam mit uns) wiederherstellen können. Bei Fragen oder Unsicherheiten können Sie sich während der Studienlaufzeit zu jedem Zeitpunkt an die Forscherin wenden.

Was passiert mit den Interviewdaten?
Die Teilnahme an der Studie ist freiwillig und vertraulich. Sie können die Studie zu jedem Zeitpunkt und ohne Angabe von Gründen unterbrechen oder abbrechen. Die von Ihnen bis zu diesem Zeitpunkt gegebenen Informationen können – ausser auf Ihren expliziten Wunsch hin – im Rahmen der Studie verwendet werden. Ihre Daten (Audiodateien, Screenshots und/oder Interviewtranskripte) werden während der Studienlaufzeit auf einem passwort-geschützten Cloud-Service (Dropbox oder OneDrive) gespeichert. Diese Daten werden maximal fünf Jahre aufbewahrt und dann permanent gelöscht bzw. sicher vernichtet. Die Daten können zur Anwendung von wissenschaftlichen Methoden durch die an diesem Projekt beteiligten Forscher eingesehen werden. Mit Ihrem expliziten Einverständnis dürfen weitere Personen Ihre Daten für Ausbildungszwecke oder wissenschaftliche Zwecke einsehen.

__ Ich stimme der Verwendung der anonymisierten Daten durch externe Forscher zur Anwendung von wissenschaftlichen Methoden durch zu.

Seite 1/2

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Nutzung des Interviewinhalts
Die Ergebnisse der Studie werden voraussichtlich sowohl gruppenintern als auch extern in Präsentationen und Veröffentlichungen, sowie wissenschaftlichen Journalen und Konferenzbänden verwendet werden.

Einverständniserklärung für Ihre Kinder
Ihren Kindern steht es unabhängig von der Einwilligung der Eltern frei die Teilnahme abzulehnen. Wenn Ihre Kinder einwilligen teilzunehmen, können sie zu jedem Zeitpunkt die Teilnahme beenden.

Einverständniserklärung
Mit Ihrer Unterschrift bestätigen Sie folgendes:

- Wir wurden von der verantwortlichen Person über die Studie und die oben aufgelisteten Bedingungen aufgeklärt.
- Wir hatten die Möglichkeit Fragen zu stellen.
- Wir haben die Antworten verstanden und akzeptieren sie.
- Wir sind mindestens 18 Jahre alt.
- Wir hatten ausreichend Zeit, uns zur Teilnahme an der Studie zu entscheiden und wir stimmen der Teilnahme zu.
- Wir geben unser Einverständnis zur Teilnahme an der Studie auch für folgende unserer Kinder: ______________________________

Diese Einverständniserklärung beeinflusst in keinerlei Weise Ihre gesetzlichen Rechte oder entbindet die Forscher und beteiligten Institutionen Ihrer gesetzlichen oder beruflichen Verantwortung. Es steht Ihnen jederzeit frei Ihre Teilnahme zu widerrufen. Wenn Sie weitere Verständnisfragen haben oder gerne weitere Informationen hätten, können Sie sich zu jeder Zeit Ihrer Teilnahme an uns wenden.

____
Name der Teilnehmer (bitte in Grossdruckschrift)

______________ ______________________________
Ort, Datum Unterschrift der Teilnehmer

Sarah Mennicken
Name der Forscherin

______________ ______________________________
Ort, Datum Unterschrift der Forscherin

Sollten Sie noch weitere Fragen bezüglich dieser Forschung und/oder Ihrer Teilnahme haben, können Sie sich an folgende Ansprechpartner wenden:

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E.2 Study Information for Children

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CASALENDAR

Danke dass Du auch Lust hast bei meiner Studie mitzumachen!

Was passiert hier? Was soll dieses Gerät bei uns daheim?
Mittlerweile kennst du mich ja schon. Ich komme immer vorbei und stelle viele Fragen zu eurem Haus und wie ihr mit der ganzen Technologie darin lebt.

Diesmal hab ich einen Computer mitgebracht auf dem eine Software läuft. Diese Software heisst Casalendar und ihr könnt sie die nächsten vier Wochen ausprobieren. Casalendar ist noch ein Prototyp, das heisst eine vielleicht nicht ganz perfekt funktionierende Software. Also manchmal bitte ein wenig Geduld haben, wenn es zum Beispiel etwas langsam ist. Aber du wirst später sehen, was du alles damit machen kannst. Z.B. kannst du sehen was das Haus so macht und auch eure eigenen Kalender. Während der Computer bei euch ist und auch danach könnt ihr mir dann sagen was ihr davon haltet, was ihr für Ideen habt, was man damit machen kann, was gut funktioniert und was weniger gut.

Und was genau soll ich tun?
Wenn du Lust hast teilzunehmen, dann kannst du in den nächsten Wochen einfach Casalendar benutzen. In Casalendar (das werde ich dir dann noch genauer persönlich erklären) kannst du Kommentare geben und ein paar Dinge einstellen. Du kannst mit dem Finger zeichnen und auch deine Stimme aufnehmen um mir zu sagen was du von Casalendar hälst. Wenn du Lust hast, kannst du auch einen Fragebogen ausfüllen. Helfe dir sehr gerne dabei.

Alle Ideen oder Kommentare die du hast, helfen mir, Casalendar besser zu machen. Ausserdem kann ich so lernen, was Leute die in einem Smart Home wohnen gerne mit diesem Haus machen würden. Wenn du auch dazu Ideen hast, kannst du das auch in Casalendar aufnehmen.

Und wenn ich keine Lust habe teilzunehmen?
Wenn du keine Lust hast oder du irgendwann keine Lust mehr haben solltest, kannst du jederzeit einfach aufhören Casalendar zu benutzen. Bitte nicht böse sein, wenn der Computer trotzdem noch ein bisschen bei euch stehen bleibt damit deine Eltern es weiterhin nutzen können.

Was machst du dann mit den ganzen Ideen und Kommentaren?
Casalendar wird auch in einem anderem Haus installiert. Ich sammel alle Kommentare und schaue mir dann an, was die Studienteilnehmer (also auch du) zu sagen habt. Dann werde ich alles zusammenfassen und aufschreiben damit andere Leute, die ähnliche Arbeit wie ich machen, daraus lernen können und bessere Software für Smart Homes entwickeln. Wenn du einen spannenden Kommentar hattest, dann wäre es toll, wenn ich diesen Kommentar als Beispiel nehmen könnte. Aber du ja nicht unbedingt willst, dass jeder wissen soll, das genau du das gesagt hast, kannst du dir einen Spitznamen aussuchen. Hast du vielleicht einen Lieblingsnamen oder bist du Fan von irgendwem?

So möchte ich gerne heissen wenn du einen Kommentar von mir verwendest:

____

Und wenn du irgendwelche Fragen hast, kannst du mich jederzeit über deine Eltern kontaktieren!

E.3 UTAUT Survey

<u>Casalendar-specific UTAUT Survey (5-item Likert)</u> *Only after deployment*

Performance Expectancy (PE)
(Does the participant believe that Casalendar is helping them to improve the interactions with their home?)

PE1:	I find Casalendar useful for interacting with my smart home.
PE2:	Casalendar helps me to identify and understand issues of the smart home configuration quickly.
PE3:	Using Casalendar increases my productivity.
PE3:	Using Casalendar increases my chances of knowing how to I'd like configure the home.
PE4:	Casalendar helps me understanding events in the home.
PE5:	Casalendar helps me to understand what the home is going to do in the future.

Effort Expectancy (EE)

EE1:	Interacting with Casalendar is clear and understandable.
EE2:	It is easy for me to become skillful at using Casalendar.*
EE3:	I find Casalendar easy to use.
EE4:	Learning to operate Casalendar is easy for me.

*Do not include, participants might think it is about using the feedback features of the prototype.

Attitude toward Using Technology (AT)

AT1:	Using Casalendar is a good idea.
AT2:	Casalendar makes interacting with the home more interesting.
AT3:	Interaction with the home using Casalendar is fun.
AT4:	I like interacting with the home using Casalendar.

Social Influence (SI)

SI1:	Members of my household think that I should use Casalendar.
SI2:	Other members of my household have been helpful in the use of Casalendar.
SI3:	In general, my household has supported the use of Casalendar.

Facilitating Conditions (FC)

FC1:	I have the knowledge necessary to use Casalendar.
FC2:	Casalendar is not compatible with other technology I use.
FC3:	A specific person (or group) is available for assistance with Casalendar difficulties.

Self-Efficacy (SE)

SE1:	I can complete my tasks in Casalendar even if there is no one around to help.
SE2:	I can complete my tasks in Casalendar only if I can ask someone for help.
SE3:	I can complete my tasks in Casalendar only if I have a lot of time.

Anxiety (AX)

AX1:	I feel apprehensive about using Casalendar.
AX2:	It scares me to think that I could accidentally change the home's settings when using Casalendar.
AX3:	I hesitate to use Casalendar for fear of making mistakes I cannot correct.
AX4:	Casalendar is somewhat intimidating to me.

Following items are not taken from standard questionnaires

Privacy and Awareness (PA)

PA1:	Casalendar revealed information about me that I would prefer not be revealed to other members of my household.
PA2:	Casalendar revealed patterns of my household's routines that I wasn't previously aware of.
PA3:	I wish I could restrict precisely which members of my household can view some of the information shown by Casalendar.
PA4:	Casalendar revealed information about me that I would prefer not be revealed to the companies that provide our smart-home technologies.
PA5:	Casalendar revealed information about me that I would prefer not be revealed to other people other than members of my household.

Behavioral Intention to Use the System (BI)*

BI1:	I intend to use Casalendar in the {next two weeks, future}.
BI2:	I predict I would use Casalendar in the future in the next month.
BI3:	I plan to use Casalendar in the future in the {next two weeks, future}.

*Decided not to use this as they will not continue to use Casalendar.

E.4 STC Survey

<u>General Survey (5-item Likert)</u> *Before AND after deployment*

Subjective Technical Competence (STC) modified [Arning & Ziefle]

STC1	Smart home technology fascinates me.
STC2	I successfully cope with technical problems in our home.
STC3	I really like to try out new smart home gadgets.
STC4	Even if technical problems in our home occur, I continue working on them.
STC5	I really enjoy solving the technical problems in our home.
STC6	Up to now I managed to solve most of the technical problems in our home, and I am not afraid of such problems in the future.
STC7	I feel uncomfortable and helpless about using the smart home technology in our home.
STC8	When I solve a technical problem in our home successfully, it mostly happens by chance.
STC9	Most technical problems in our home are too complicated for me to deal with.

All following items are not taken from standard questionnaires

STC10	If I wish to change the configuration of our home, I do it by myself.
STC11	I ask other household members for help to solve technical problems in our home.
STC12	I ask people other than my household for help to solve technical problems in our home.
STC13	When I try something new, I don't mind potential consequences because I know how to revert the changes

Social Effects (SE):

SE1	I often talk about smart home functionalities with the whole household.
SE2	I feel that we're relying on the smart home technologies too much.*
SE3	I'm not afraid to bother someone else to program my ideas in the smart home.**
SE4	I have privacy concerns about my smart home.
SE5	The smart home often triggers conversations around our activities/routines/behavior.
SE6	The smart home helps our household understand what everyone else is up to.
SE7	It is necessary to communicate personal needs regarding the smart home to each other***
SE9	My routines/behaviors adapted to the way the smart home works.

* Taken from Passive User Study: "I'm bothered that sometimes I rely on automatic systems too much and stop enjoying the process of having my house lit by candles" P6

**Perceived 2nd person view of effort of reprogramming the home – or personality

***Could be lower or higher after using Casalendar. Lower when self-efficacy increases, higher when there are more interesting things to discuss about based on what they see on Casalendar

Trust and Understanding (TU):

TU1	I often don't understand the underlying reasons when things happen automatically in the home.
TU2	If something happens automatically in the home, I know why it happened.
TU3	Sometimes the home does something that I didn't expect.
TU4	Sometimes I expected the home to do something, but it didn't.
TU5	I trust that the home is doing what it's programmed to do.

TU6	If I don't understand the behavior of the home directly, I know how I can find it out.
TU7	I know all the functions that our smart home is configured to perform.

Interest and Initiative (II):

II1	I often ask someone at home to technically realize my ideas for changes or adjustments.
II2	I have several ideas of how to change the configuration of the smart home to make it more suitable for our routines.
II3	The current configuration of our home fits well into our routines.
II4	I enjoy adding new features to the home.
II5	Many features were added without a real need for them.

Perceived Benefits (PB):

PB1	I have fewer things to worry about because of the smart home technology.
PB2	Our smart home gives me peace of mind when I am not at home.
PB3	Our smart home meets my needs and matches my routines very well.
PB4	I have more things to worry about because of the smart home technology.

Extent of Usage (EU):

EU1	I continuously adapt the home to our needs.
EU2	I rarely change the configuration of the home.
EU3	For guests, special events, or holidays I manually overwrite smart home functions.

EU4	For guests, special events, or holidays I adjust the smart home configuration.
EU5	I'm using the whole potential of what I could do with the smart home functions.

Awareness (AW)

If you had an afternoon free to change something in your smart home, what would your changes be?

Please rank those ideas for changes in the order of in which you'd work on them.

On a scale from 1(not at all) to 5(very much), how important is that change for you?

Is there a particular situation that makes you want that change? If so, please describe that situation.

Please describe how often this situation has occurred or is occurring.

E.5 Interview Protocol

1/2

Casalendar Post-Deploy Protocol

Start by: tell me a little about how you used Casalendar in the last 4 weeks?
How often?
At specific times?
What did you look at specifically?
Who of you liked it most/least? How come?

What did you like most about it?
[Any specific functions?
Parts of the visualization?
Fake events?
Feedback function?]

What did you like least?

How useful was it for you? Why? Why not?
[Do you think this would have been different if you used it earlier on?]

Did you change how you interact with your home in any way?
Do you think these changes will persist after you stop using Casalendar?

Did your use of it or perspective of it change over the course of the 4 weeks and if so, how? Would your use have been different at another time of the year? How and why?
[what kind of external stuff might have affected how they used it? I'm thinking of stuff like the kittens, which you already know about. Might there have been other events or happenings in the family that caused more or less use of the system that you don't know about, e.g., a burglary in the neighborhood caused them to start checking their entry/exit instances more frequently?]

Did you get any insights about your home? The events that take place in it?
Any behavior that you know more about in detail now?
[Do they say, "that [something in the data] was because of [x] -> increased understanding]

There was also the prediction feature? Did you use it?
If so, what was useful about it? How were you using it?
If not, any sense for why?

You mentioned in your feedback…
H1: more control of the home]
- **Anpassungen Helligkeitssensoren für die Markisensteuerung, festgestellt über Wetterbeobachtungen, welche Informationen habe in Casalendar dafür gefehlt?**

-

H2:
- **having a focus on exceptions**
- **things that didn't work as they're supposed**
- **things happening in the future**

Can you elaborate on that? Why? Ideas for how it should be ideally included?

You couldn't really change anything in the interface. Were there situations in which you would have wanted to?

Did you discuss Casalendar with the family? What did you talk about?
[Do any privacy themes arise? whether anyone had problems with how the family used it. e.g., someone didn't like that others in the family were now explicitly looking at the house stuff all the time, whereas previously it had all just been in the background and the family could mostly "ignore" the house?]

Did you have guests in the last months? Did you mention/show/use Casalendar? Tell me about that.

In some earlier comments it was mentioned to keep Casalendar as a note function. **For how long would you like to be able to go back in the past?** In which situations would you do that?

E.6 Casalendar Manual

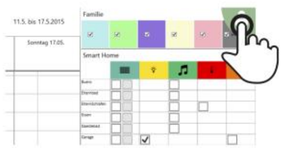
CASALENDAR

Einloggen

1 Bitte logge dich immer durch Klicken auf deinen Namen ein, wenn du Casalendar benutzt.

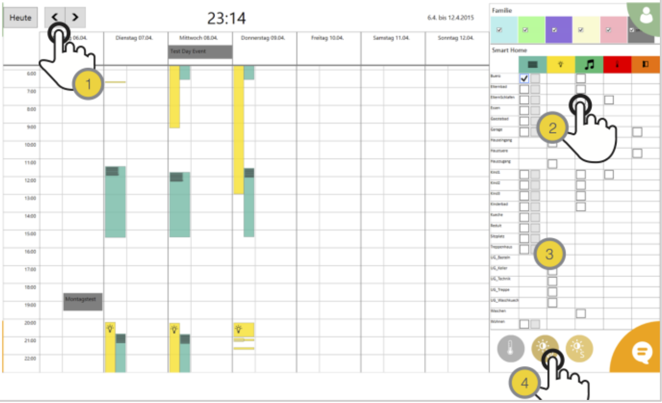
Ausloggen

2 Falls du dich ausloggen willst, kannst du das über den Knopf rechts oben machen.



Kalenderfunktionen

In Casalendar kannst du eure eigenen Kalender sehen, sowie was euer Smart Home macht und gemacht hat.



1. Wenn du dir eine andere Woche anschauen möchtest, kannst du das über die Knöpfe links oben machen. Der "Heute"-Knopf bringt dich immer zu der aktuellen Woche zurück.

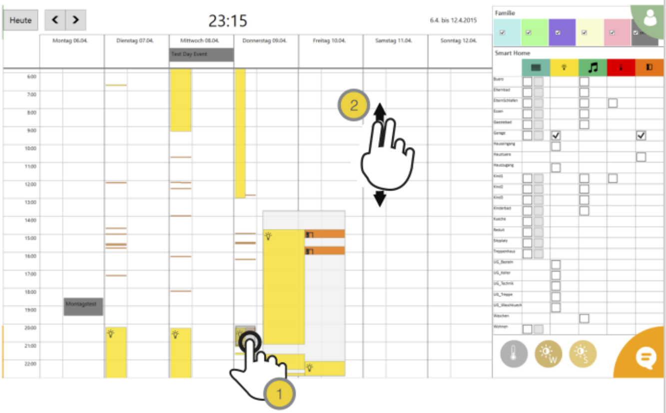
2. Mit der Tabelle auf der rechten Seite kannst du verschiedene Funktionen oder Räume die dich interessieren durch einen Klick ein- oder ausblenden. Dadurch wirst du im Kalender Einträge von eurem Haus sehen. Du kannst auch auf die Raumnamen oder auf die Kategorie-Symbole klicken um mehrere Dinge gleichzeitig anzuzeigen.

3. "Zukunftsvorhersage": Wenn du die leicht grauen Kästchen in der Tabelle klickst, dann wird angezeigt was euer Smart Home vielleicht in den nächsten Wochen mit den Jalousien macht.

4. Mit den drei runden Buttons kannst du Aussentemperatur, Helligkeit im Westen und Helligkeit im Süden anzeigen.

Bedienung

Zwei Funktionen, die euch helfen sollen Casalendar zu bedienen.



1. Wenn die Einträge im Kalender zu klein sind zum Antippen, dann kannst du einmal in die Nähe tippen und du wirst danach ein vergrössertes Fenster sehen.

2. Um dir eine anderen Tageszeit anzuschauen, kannst du mit zwei Fingern die Ansicht scrollen.

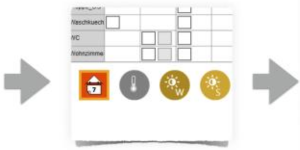
Neue Einträge

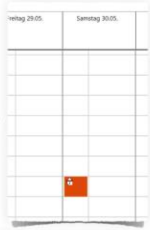
Um Ideen für diese Studie zu sammeln und dir die Möglichkeit zu geben eine Funktion mit dem Kalender zu steuern, kannst du neue Einträge erstellen.

1 Auf der rechten Seite seht ihr einen orange-farbigen Knopf auf den man klicken kann um neue Einträge zu erstellen.

Wenn ihr darauf geklickt habt, dann seht ihr einen orangenen Rand.

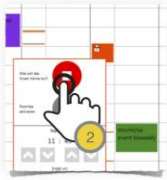
Dann kannst du in den Kalender klicken um den Eintrag zu der angeklickten Zeit zu erstellen.





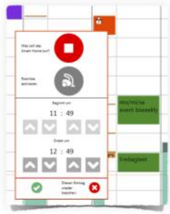
2 Hier Du kannst eine Audioaufnahme machen und sagen was das Haus in der angezeigten Zeit machen oder vielleicht nicht machen sollte.

Das könnten Funktionen sein, die es bereits gibt (z.B., dass die Jalousien rauf- oder runtergehen) oder aber auch Sachen von denen du dir wünschst, dass das Haus es tun würde (z.B. dein Zimmer aufräumen, den Ofen vorheizen, …).



3 Oder du kannst per Klick auf den entsprechenden Knopf:
1) das Licht im Kinderbad anschalten für den gewählten Zeitraum.
2) Oder die Schlafzimmer-Jalousien blockieren für den gewählten Zeitraum, so dass sie zu dem Zeitpunkt weder hoch- noch runtergehen.
3) Den Roomba starten und beenden

Der kleine Knopf ganz unten löscht diesen Eintrag wieder.

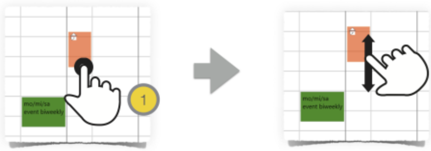


Neue Einträge

Um Ideen für diese Studie zu sammeln und dir die Möglichkeit zu geben eine Funktion mit dem Kalender zu steuern, kannst du neue Einträge erstellen.

1 Um den Zeitpunkt des Eintrages zu verschieben, musst du etwas länger auf dem Symbol gedrückt halten.

Es wird dann leicht transparent und du kannst es dann verschieben.



2 Wenn du länger gedrückt gehalten hast und dann wieder loslässt, siehst du zwei Kreise.

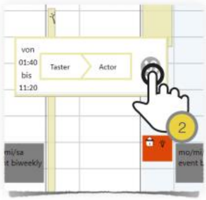
Wenn du mit dem Finger an den Kreisen ziehst, kannst du den Eintrag verlängern oder verkürzen.

3 Um dir zu helfen wird beim Bewegen die Start- und Endzeit angezeigt.

Detailansicht

1 Wenn du auf einen dieser Einträge klickst, dann wirst du ein paar Details sehen.

2 Wenn du auf Kalendereinträgen am heutigen Tag klickst, dann kannst du dort auch Lichter wieder aus machen indem du auf den geschlängelten Pfeil-Knopf klickst.



Kommentieren

Bei dieser Studie brauche ich ganz viel Kommentare und Ideen von dir! Damit das möglichst einfach für dich ist, kannst du dies auf folgende Weise tun.

1 Rechts unten gibt es einen orange-farbigen Knopf mit Sprechblase. Wenn du darauf klickst, bist du im "Kommentieren" -Modus.

Das siehst du auch dadurch, dass der Bildschirm dann einen orangenen Rand hat. In diesem Modus kannst du deine Gedanken, Ideen, und Kommentare aufnehmen.

2 Mit deinem Finger kannst nun du auf dem Bildschirm malen. Du kannst malen oder markieren was du willst um deine Gedanken auszudrücken. Hier ein paar Ideen: du kannst Sachen durchstreichen, Pfeile zeichnen, oder ein oder mehrere Kalendereinträge umkreisen.

Kommentieren

Bei dieser Studie brauche ich ganz viel Kommentare und Ideen von dir! Damit das möglichst einfach für dich ist, kannst dies auf folgende Weise tun.

1 Mit dem Sprechblasenknopf kannst du deine Gedanken, Ideen, Kommentare aufnehmen.

Wenn du auf den Sprechblasen-Knopf drückst, wird der Knopf rot und zeigt dadurch an, dass er deine Stimme aufnimmt.

Wenn du wieder draufklickst, ist die Aufnahme gestoppt.

Der Knopf wird dann grün und zeigt einen Pfeil an. Falls du dir deine Aufnahme nochmal anhören willst, kannst du einfach nochmal auf den Knopf drücken.

2 Du kannst deine Zeichnung und deine Audio-Aufnahme mit den jeweiligen "Löschen" Knöpfen wieder entfernen.

Wenn du zufrieden bist mit der Aufnahme und/oder deiner Zeichnung, kannst du auf das grüne Häkchen rechts unten klicken und du kannst wieder Casalendar normal benutzen.

Diese Studie

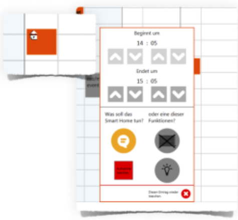
Um die ein paar Ideen zu geben, was du bei dieser Studie so alles kommentieren könntest, hier ein paar Beispiele.

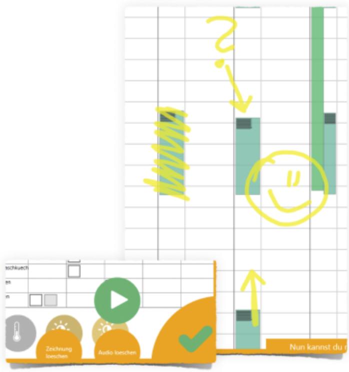
Dinge, die du im Haus gern ändern würdest.

Klick auf den orangenen Knopf, male was du gern ändern würdest und benutze dann die Audioaufnahme um zu beschreiben, **was** du gerne ändern würdest.

Bitte erkläre auch **warum** du das gerne ändern wüdest (z.B. weil es ein Konflikt mit etwas anderem ist, weil es etwas verbessern würde, weil es eine einmalige Ausnahme ist, oder einfach nur weil das heute besser zur Laune/Stimmung passt...)

Auch bei diesen Einträgen kannst du Audio-Kommentare hinterlassen.





Dinge, die dir auffallen oder zu denen du andere Ideen hast.

Appendix F. **Personality Study**

F.1 Consent Form

Informed Consent "Experiences with a Smart Home"

Dear participant,

We are inviting you to participate in our study on home automation. We conduct this scientific study to gain a better understanding of the needs of inhabitants of homes with building technologies and to contribute to the development of future technologies of such kind. In this specific study we are interested in investigating interactions between people's personalities and their perceptions of different smart home behaviors.

What will we ask you to do?
If you agree to participate in this study, we will ask you for three things:

1. Fill out some questions about your personality.
2. Take part in two guided walkthroughs of a smart home scenario.
3. Fill out a questionnaire after each scenario.

What type of personal information will be collected?
For statistical information we will ask you for your age, gender, occupation and several questions regarding your household. Furthermore we will ask you about your personality. All data is collected anonymously. You will remain anonymous in any written publication or presentation based on this research.

Are there risks or benefits when participating?
There are no particular risks associated with the study beyond those associated with normal everyday activity.

What happens to the questionnaire data?
Participation in the study is voluntary and confidential. You are free to withdraw your participation at any point during the study, without needing to provide any reasons. Any information you contribute up to the point at which you choose to withdraw will be retained and used in the study, unless you request otherwise. The results of this study can potentially appear in both internal and external presentations and publications.

With your signature on this form you confirm the following statements:

- An investigator explained the study and the listed conditions to me. I had the opportunity to ask questions. I understood the answers and accept them.
- I am at least 18 years old.
- I had enough time to make the decision to participate and I agree to the participation.

In no way does this waive your legal rights or release the investigators or involved institutions from their legal or professional responsibilities. You are free to withdraw from this research project at any time. You should feel free to ask for clarification or new information at any time during your participation.

Participant's name

Location, Date Participant's signature

F.2 Questionnaire

Print version

Questionnaire

1 Welcome

Please state the number you were assigned by in the study.

Age

Gender

- Female
- Male

Background

Occupation

Field of study

How many people live in your household (including you)?

If there are multiple people in your household, do you live with your family or other people? Please specify the relationship.

How often do you have guests over?

- multiple times a week
- once a week
- multiple times a month
- once a month
- multiple times a year
- once a year
- less than once a year

Explain in one sentence: What do you think a smart home is?

Do you have any sort of automated functionalities at home (e.g. Philips hue, motion sensors, ...)? If so, please indicate what.

- No
- Yes

How well do the following statements describe your personality?
I see myself as someone who...
[Ich...]

We added the German translation for your better understanding.

	not at all	not really	undecided	somewhat	very much
is reserved. [bin eher zurückhaltend, reserviert.]	○	○	○	○	○
is generally trusting. [schenke anderen leicht Vertrauen, glaube an das Gute im Menschen.]	○	○	○	○	○
tends to be lazy. [bin bequem, neige zur Faulheit.]	○	○	○	○	○
is relaxed, handles stress well. [bin entspannt, lasse mich durch Stress nicht aus der Ruhe bringen.]	○	○	○	○	○
has few artistic interests. [habe nur wenig künstlerisches Interesse.]	○	○	○	○	○

is outgoing, sociable. [gehe aus mir heraus, bin gesellig.]	○	○	○	○	○
tends to find fault with others. [neige dazu, andere zu kritisieren.]	○	○	○	○	○
does a thorough job. [erledige Aufgaben gründlich.]	○	○	○	○	○
gets nervous easily. [werde leicht nervös und unsicher.]	○	○	○	○	○
has an active imagination. [habe eine aktive Vorstellungskraft, bin phantasievoll.]	○	○	○	○	○

2 Thanks for the first part

Thank you for filling out the first part of the questionnaire.
Please let us know when you reached this page, so we can walk you through the first scenario.

3 After first scenario

How much did you like the overall experience in this Smart Home?

not at all	not really	undecided	somewhat	very much
○	○	○	○	○

What did you like about it?

What did you dislike about it?

How did you perceive the home you experienced in this scenario?

	not at all	**not really**	**undecided**	**somewhat**	**very much**
How energetic (lebhaft) did you perceive this home?	○	○	○	○	○
How social (gesellig) did you perceive this home?	○	○	○	○	○
How creative (kreativ) did you perceive this home?	○	○	○	○	○
How imaginative (einfallsreich) did you perceive this home?	○	○	○	○	○
How insecure (verunsichert) did you perceive this home?	○	○	○	○	○
How moody (launisch) did you perceive this home?	○	○	○	○	○
How trustworthy (zuverlässig) did you perceive this home?	○	○	○	○	○
How sensitive (einfühlsam) did you perceive this home?	○	○	○	○	○
How organized (organisiert) did you perceive this home?	○	○	○	○	○

How responsible (verantwortungsvoll) did you perceive this home? ○ ○ ○ ○ ○

How strongly do you agree or disagree with following statements?

	strongly disagree	disagree	undecided	agree	strongly agree
I'd trust the home I experienced in the scenario to automatically execute things the way I want in the future. Please explain why. (optional)	○	○	○	○	○
The home I experienced in the scenario would adjust to my future needs well. Please explain why. (optional)	○	○	○	○	○
The actions of the home I experienced in the scenario were pleasantly surprising to me. Please explain why. (optional)	○	○	○	○	○
The automated actions in the home I experienced in the scenario were understandable to me. Please explain why. (optional)	○	○	○	○	○
I felt sufficiently informed about events and changes in the home I experienced in the scenario. Please explain why. (optional)	○	○	○	○	○
I felt comfortable about my privacy in the home I experienced in the scenario. Please explain why. (optional)	○	○	○	○	○
I would enjoy living in a home that provides such an experience. Please explain why. (optional)	○	○	○	○	○
If you live with other people: I'd have fewer conflicts with my other household members in the home I experienced in the scenario compared to a home without any automation. Please explain why. (optional)	○	○	○	○	○
I'd have to intervene in such a home's actions frequently. Please explain why. (optional)	○	○	○	○	○

Do you have any other comments?

Please let us know when you have finished with this page. You will be guided through the second scenario.

4 Thanks for the second part

Thank you for filling out the second part of the questionnaire.
Please let us know when you reached this page, so we can walk you through the second scenario.

5 After second scenario

How much did you like the overall experience in this Smart Home?

not at all	not really	undecided	somewhat	very much
○	○	○	○	○

What did you like about it?

What did you dislike about it?

How did you perceive the home you experienced in this scenario?

	not at all	not really	undecided	somewhat	very much
How energetic (lebhaft) did you perceive this home?	○	○	○	○	○
How social (gesellig) did you perceive this home?	○	○	○	○	○
How creative (kreativ) did you perceive this home?	○	○	○	○	○
How imaginative (einfallsreich) did you perceive this home?	○	○	○	○	○
How insecure (verunsichert) did you perceive this home?	○	○	○	○	○
How moody (launisch) did you perceive this home?	○	○	○	○	○
How trustworthy (zuverlässig) did you perceive this home?	○	○	○	○	○
How sensitive (einfühlsam) did you perceive this home?	○	○	○	○	○
How organized (organisiert) did you perceive this home?	○	○	○	○	○
How responsible (verantwortungsvoll) did you perceive this home?	○	○	○	○	○

How strongly do you agree or disagree with following statements?

	strongly disagree	disagree	undecided	agree	strongly agree
I'd trust the home I experienced in the scenario to automatically execute things the way I want in the future. Please explain why. (optional)	○	○	○	○	○
The home I experienced in the scenario would adjust to my future needs well. Please explain why. (optional)	○	○	○	○	○
The actions of the home I experienced in the scenario were pleasantly surprising to me. Please explain why. (optional)	○	○	○	○	○
The automated actions in the home I experienced in the scenario were understandable to me. Please explain why. (optional)	○	○	○	○	○
I felt sufficiently informed about events and changes in the home I experienced in the scenario. Please explain why. (optional)	○	○	○	○	○

I felt comfortable about my privacy in the home I experienced in the scenario. Please explain why. (optional)

I would enjoy living in a home that provides such an experience. Please explain why. (optional)

If you live with other people: I'd have fewer conflicts with my other household members in the home I experienced in the scenario compared to a home without any automation. Please explain why. (optional)

I'd have to intervene in such a home's actions frequently. Please explain why. (optional)

Do you have any other comments?

6 Summary

Which smart home experience did you like more?

Scenario 1 Scenario 2

Please explain why.

Please select and drag all personality traits that you would like a smart home (in general) to have to the right and rank them *starting with the most wanted trait.*

You can re-rank them and remove them again by dragging them back to the left.

energetic (lebhaft)

social (gesellig)

creative (kreativ)

imaginative (einfallsreich)

insecure (verunsichert)

moody (launisch)

trustworthy (zuverlässig)

sensitive (einfühlsam)

organized (organisiert)

responsible (verantwortungsvoll)

self-confident (selbstbewusst)

encouraging (aufmunternd)

introverted (introvertiert)

inactive (untätig)

stubborn (stur)

narrow-minded (engstirnig)

aggressive (aggressiv)

inflexible (unflexibel)

disorganized (unorganisiert)

irresponsible (verantwortunglos)

7 Summary 2

Please select and drag all personality traits that you would NOT like a smart home (in general) to have into the box to the right and rank them *starting with the most unwanted trait.*

You can re-rank them and remove them again by dragging them back to the left.

energetic (lebhaft)

social (gesellig)

creative (kreativ)

imaginative (einfallsreich)

insecure (verunsichert)

moody (launisch)

trustworthy (zuverlässig)

sensitive (einfühlsam)

organized (organisiert)

responsible (verantwortungsvoll)

self-confident (selbstbewusst)

encouraging (aufmunternd)

introverted (introvertiert)

inactive (untätig)

stubborn (stur)

narrow-minded (engstirnig)

aggressive (aggressiv)

inflexible (unflexibel)

disorganized (unorganisiert)

irresponsible (verantwortunglos)

Please explain your choices.

8 Endseite

Thank you for participating in this study.

F.3 Steps of the Study Scenarios and Responses of the Home Design

Inhabitant Use Case	Component	Cheerful-Extroverted Home	Conscientious-Kind-Calm Home	Design Reasoning/ Comment
Wakes up	Alarm Clock	funky song	alarm sound and classical song	different level of volume and genre
		lights in different bright colors	lights in mute blue and yellow colors	color choice based on (Wright, Wallace, & McCarthy, 2008)
	Weather	same voice and content		
	Calendar Interface	same user content		
		proposes barbecue in the evening and invites friends, if confirmed	displays icon for sunglasses or umbrella based on weather	social life and proactivity vs. diligent and organized, words choice inspired by (Hirsh & Peterson, 2009; Mehl et al., 2006; Yarkoni, 2010)
Goes to bathroom	Reaction to Mood	lights turn blue		color choice based on (Wright et al., 2008)
		tells a joke	shows sad smiley on screen	creative and humorous vs. sensitive and quiet
	Coffee	proactively prepares coffee	asks participants and whether that should become the default	proactive vs. obedient and adaptable
	Reaction to Mood	lights turn green	asks if inhabitants wants to hear music or news	color choice based on (Wright et al., 2008)
	Reminder	tells inhabitant to hurry up for meeting	informs inhabitant about time to go to work based on traffic conditions, suggests hurrying up	different granularity of details, words choice inspired by (Hirsh & Peterson, 2009; Mehl et al., 2006; Yarkoni, 2010)
Leaves home	Reminder Wallet	Roomba gets into participant's way and guides him to location of wallet, where it makes a dance	Roomba drives silently to location of wallet, where it makes a sound	interruptive and energetic vs. subtle and quiet
	Reminder Sunglasses	ø	based on weather, reminded by voice	different level of organized and trustworthy
	Voice & Power off	wishes a good day and turns off all lights and screens		
	Roomba	starts cleaning		
Comes home	Lights	turn on in color loop	turn on in white light	color choice based on (Wright et al., 2008)
	Voice	greets inhabitant		words choice inspired by (Hirsh & Peterson, 2009; Mehl et al., 2006; Yarkoni, 2010)

	Information Door	informs inhabitant about person at front door during his absence		
		Ø	sends picture of person to participant's phone and asks if it should always send such informative messages	different granularity of details and level of security concern, responsibility, and trustworthiness
Sits on couch	TV	turns on and suggests to resume episode from last time		
	Propositions	activities like skyping with family members or taking a walk	items from the chores list like doing the laundry	social life vs. diligent about chores
	Voice	suggests inhabitant to go to bed earlier		based on morning mood
Goes to bathroom	Reaction to Mood	comments on improved mood and changes lights to green		color choice based on (Wright et al., 2008)
		comment through voice output	comment through screen	talkative vs. subtle and quiet
Goes to bed	Music	soul music	classical music	different level of volume and genre
	Alarm Clock	Ø	asks if set time suits inhabitant	different level of responsible and trustworthy
	Voice & Power off	wishes a good night and switches off all lights, screens, and music after a while		

Appendix G. **EmotoCouch Study**

G.1 Emotional Association

The left chart in Figure G-1 shows the percentage of survey responses where participants associated the intended emotion with the picture they saw. As the first bars for each emotion in the left chart show, Angry and Calm had the most participants associating the color shown with the emotion intended. However, both are still relatively low at 42% and 46% of participants respectively. Participants were very selective in choosing Angry and rarely associated it incorrectly with any other emotion (88% of the 90 times Angry was chosen it was correct). Conversely, Calm has high percentage of correct associations because participants frequently selected this emotion overall. Only 29% of the 310 times participants labeled a colored couch Calm was it the intended emotion.

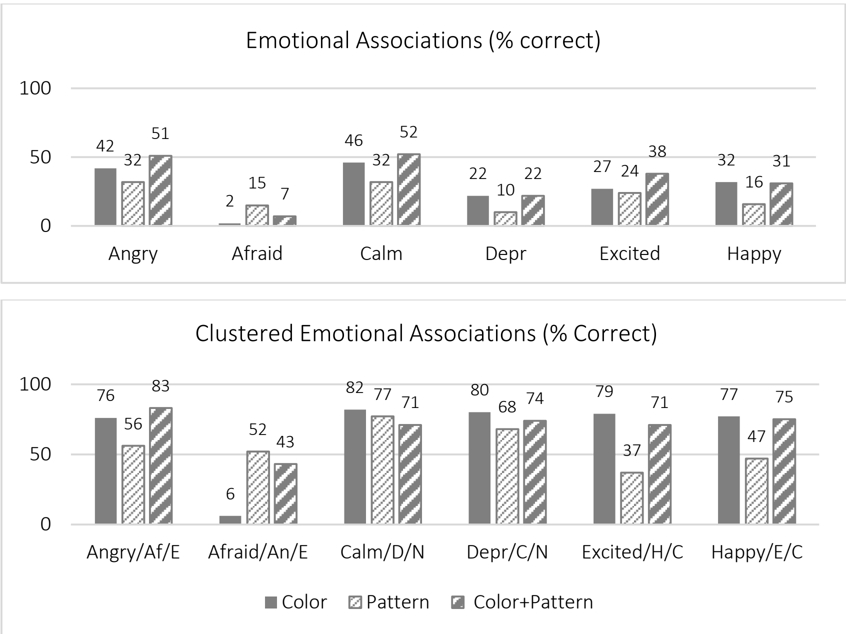


Figure G-1: (Left) Percentage of online survey respondents who associated the intended emotion with the Color, Pattern, and Color+Pattern combined. (right) The chart clusters emotions that have similar characteristics in the Circumplex model. For example, Angry, Afraid, and Excited all have high arousal. Higher % correct for clustered emotional suggests designs are achieving an emotional response similar to what was intended but not exactly what we wanted to convey.

Only 2% of participants chose Afraid for the salmon color we selected, making it very unsuccessful. Instead, most people associated it with Calm (37%), Neutral (27%) or Happy (20%). For the remaining three emotions, 32% associated green with Happy, 27% yellow with Excited, and 22% associated purple with Depressed/Sad.

When investigating which emotions were selected instead of the ones intended by our designs, we found that respondents often chose emotions with similar characteristics in the Circumplex Model. Thus respondents were associating the design with a similar emotion, just not the exact one we intended. We clustered emotions as follows to test this:

High Arousal Emotions: Angry, Afraid, and Excited are at the top of the Arousal axis of the Circumplex model. We grouped these three to analyze Angry and Afraid responses. Particularly for Angry this improved accuracy. When shown the red "Angry" couch (Figure G-1 (right), Angry/Af/E Color) a total of 76% of responses were one of these three emotions, primarily Angry (42%) and Excited (31%).

Low Arousal Emotions: On the opposite end of the Arousal axis are Calm and Depressed/Sad. We also found that participants often chose "Neutral" when presented with the colors we had selected for Calm (blue) and Depressed/Sad (purple). Clustering these three responses for when participants saw the Calm and Depressed designs accounted for 82% and 80% of responses (Figure G-1 right chart).

Positive Valence Emotions: Happy, Excited, and Calm are emotions considered positive. For the colors presented for Excited (yellow) and Happy (green), grouping responses of these three positive valence emotions accounted for 79% and 77% of responses.

We analyzed participant responses by gender, age groups by decade, current energy level (arousal) and how respondents were feeling (valence), but did not find significant differences in the percentage of emotions participants selected that matched the intended emotions among these groups.

Participants' qualitative feedback, both on the survey and in the lab study, highlights factors that influenced people's association of a color to an emotion. It was common for participants to say the color reminded them of something. For example, 15 survey respondents said the yellow color we designed for Excited reminded them of the sun (M128: *"It's bright, very bright! Like the sun,"* M55: *"It's the same color as the sun! It likes to be outside"*). Seventeen respondents connected the Green color used for Happy with nature, many mentioning grass and making a positive association (M65: *"The color green I associate with grass. I like to lay in the grass and relax,"* M102: *"the green color reminds me of grass on a calm day"*).

Confirming related work, we observed people tended to perceive a design intended to convey a negative valence emotion (Angry, Afraid, Depressed/Sad) as positive if it showed a color they liked. For example, all eleven participants that explicitly described liking the salmon color used for Afraid associated it with positive valence emotions (Excited, Calm, Happy) or Neutral. In the lab study, because of the LEDs brightness, Afraid was a rather vivid pink and mentioned as a favorite color several times which also led to associations with positive emotions. For Angry (red) and Depressed/Sad (purple) we observed the same effect, all participants that mentioned liking that color associated it with emotions with positive valence or Neutral.

As expected, we also observed instances where learned cultural color associations were dominant. This seemed most prevalent for Angry (C10: *"Red is usually the color of anger and bad stuff, aggressive"*) and Calm (M62: *"Blue is calming to me,"* M85: *"calming blue color"*). These comments validated the design approach we took building on these known associations. Some participants mentioned the color temperature or saturation as the reason for choosing a particular emotion. For example: C8: *"Cool colors are used for sad and calm,"* and C2: *"The color, it's like a fun color […] a bright and vivid color."* In fact, among survey respondents the word "bright" was mentioned 44 times when describing the yellow color that we chose for Excited.

G.2 Pattern Association

The match between the intended emotion for a pattern and the emotion participants actually associated with it was not very successful as Figure G-1 left chart shows. Participants seemed to struggle with pattern association and gave a neutral response much more frequently than when associating colors to emotions. Across the six emotions, Neutral was specified in 29% of total pattern responses, compared to 13% of total color responses. Even considering the clustered responses, the patterns were not very successful as shown in the right chart of Figure G-1. Calm (77%) and Depressed/Sad (68%) have the best accuracy because they include Neutral responses.

Qualitative feedback suggests the lack of color on the couches with only patterns may have caused the prevalence of Neutral responses as color appeared to be the driving factor for some participants in determining the emotion. 82 participants (59% of respondents) made a comment about lack of color, and some did so for multiple patterns (e.g. M130: *"The black and white with no color seems to make this couch feel neutral,"* M87: *"white makes this couch feel neutral,"* M71: *"neutral white color"*).

The different interpretations participants had of the same pattern also demonstrate why conveying the emotion we intended through patterns was so challenging. This was most striking for the Excited pattern. 44 respondents made negative comments using words like childish, uncomfortable, angry (e.g. M108: *"The squiggles are very childish", M127: "The coils look bunched and uncomfortable"*). Another 31 respondents made positive comments using words like fun, happy, playful (e.g. M96: *"Squiggly pattern makes it excited."* M11: *"Squiggly lines are very playful"*).

Similarly, for the dropping lines used for Depressed/Sad, 30 participants made explicitly negative comments (e.g. M44: *"The lines remind me of prison bars"*) while 24 made positive ones (e.g. M122: *"evenly space lines are calming"*). For other patterns, when participants made comments about positive or negative aspects of the pattern, one type dominated. For example, positive descriptions of the curves or "waves" of the Calm pattern (39 mentions) and negative ones for the zig zag lines of Angry.

G.3 Haptics

The emotional associations made by the 14 lab study participants who experienced the haptics-only segment suggest it was even more difficult to associate emotions with haptics in isolation than patterns. The fast jerky feedback used for Angry was most successfully associated to the desired emotion (31%, 5 of the 16 responses for the Angry vibration). The steady drumlike feedback designed for Calm was most consistently associated across respondents, albeit with Depressed/Sad instead of Calm (38%, 6 of the 16 responses for the Calm vibration). Comments highlighted the lack of energy in the vibration, e.g. P6: *"Very faint, not a lot of energy."*

Clustering responses improved results for High Arousal emotions. The vibration for Angry was categorized in 94% of responses as a High Arousal emotion (Angry, Afraid, or Excited) and the vibration for Afraid in 76% responses. In general, regardless of the emotion we were attempting to convey, haptic vibrations were more frequently associated with High Arousal emotions. 51% of all 98 associations made by participants in haptics-only were either Afraid (22.4%), Angry (14.3%), or Excited (14.3%).

Participants tended to associate haptics with active physical movement (P5: "Pulses are a little bit different in rhythm, like it is dancing almost," P6: "Running at a slow pace"), or physical human behaviors (C1: "Vibration reminds me of regular breathing motion," P1: "It feels to me if you get nervous about something, you start shaking"). When participants described vibrations as animal-like (P1: "a small animal relaxing," C11: "A cat purring, when a cat is purring it feels calm"), they were more likely to associate them with Calm.

Overall, although haptics reminded several participants of massage chairs, many participants reacted to incorporating haptic feedback into the couch with skepticism. Some found the vibrations irritating and in a few cases it even made them want to stand up (C12: *"Almost kind of feels uncomfortable, eeeh, it doesn't feel right"*). A field study would be important to evaluate the appropriate role of haptics in furniture so people could experience the vibrations over a longer time period and perhaps tune them to their preferences.

G.4 Design Combinations

Ideally the combination of Color+Pattern or Color+Pattern+Haptics would lead to higher percentage of correct emotional associations than any one cue alone. We achieved this for some emotions, but had no improvement or struggled for others, where it seemed that dissonance between the emotions participants associated with different cues caused confusion. For example, in the online survey, clustered emotional associations for Color+Pattern had fewer correct associations than clusters for Colors only in all cases except Angry.

(Slightly) Better Together

Figure G-1 left chart shows that for online survey respondents the combination of color and pattern did increase the number of correct associations for Angry (51%), Calm (52%), and Excited (38%). For example, for Calm, participants perceived the wavy lines as a good match with the blue color, which reminded them of the ocean and led to an association with the intended calm emotion.

In the lab study, participants that saw Color+Pattern+Haptics had more correct associations for Calm and Excited than participants who saw only Color+Pattern, suggesting the vibrations selected helped convey those emotions. The haptic design presented for Angry caused considerable confusion. Participants in the Color+Pattern condition corrected identified the Angry design 75% of the time (12 of 16 associations, people could choose multiple emotions) compared to only 13% of responses for participants with haptic feedback (3 of 23 associations). Including the Angry vibration caused participants to mostly choose either Afraid or Excited, which at least are also High Arousal emotions. Comments about the Angry vibration included: P5: *"Because it almost makes it feel like it's shaking from fear that corresponds with the scribbles."* and C13: *"Kind of a little scared. Just the jittery nature of the vibration and also the color and the wavy things."*

Stayed the Same Together

For Depressed and Happy, the colors (purple and green) appear to dominate people's association with an emotion and in the online survey the combination of Color+Pattern was no better than Color alone. In the lab study, unfortunately again inclusion of haptic feedback led to fewer correct associations for both Depressed and Happy. The combination of color, pattern and haptic feedback for Depressed/Sad caused some confusion. For example, P1: *"I think the straight lines don't match with being depressed or sad [..] maybe that they are diagonal, slow wave or something instead,"* and C11: *"The vibration doesn't have anything to do what they couch looks like."*

Still Bad/Worse When Together

Our choices of cues for Afraid remained unable to convey that emotion to survey participants in the Color+Pattern condition. In fact, the pattern alone did best for Afraid in the online survey (still low at 15%) and haptics-only did best in the lab study (24% of responses made correct association). For design combinations, comments suggest the perception of a mismatch between color and pattern: P10: *"The pink seems a lot warmer than the design kind of give in, sharp edges on some and swirls on the other,"* as well as haptic and visual feedback (P13: *"The squiggles seem random where the vibration is consistent"*).

Kids, Parents, and Emotional Associations

Furniture in a home is used by all the residents. We included parent/child pairs in our lab study to assess potential differences in emotional associations and preferences between family members. We found no differences in favorite colors among parents and children with the exception that three kids liked purple (our Depressed/Sad color) and none of the parents did. At the end of the study when family members worked together to label the six designs, although there were some discussions, people found it easy to come to agreement. Data from the lab study on the favorite and least favorite designs of participants indicates that neither parents nor kids liked Angry, and that parents tend to favor Calm while the kids did not show a clear favorite.

From Emotions to Emotional Quadrants

In many cases we could not successfully convey the single unique emotion we were trying to represent. Table G-1 consolidates our interpretation of design feedback received with a focus on promising future directions. Some issues are likely the result of making incorrect design choices. For example, related work that inspired the patterns gave rather vague descriptions of the looks (e.g., "ill-defined shapes" for Depressed/Sad) and often there was a wider range of potential pattern characteristics. Thus, our designs might not actually incorporate those guidelines sufficiently. Experimenting with more color variation and a wider range of patterns could help to improve the emotional associations of design combinations.

Table G-1: Consolidate feedback on designs and ideas about promising future directions

Attempted Emotion	Desired	Design Association	Future directions
Excited	✓	✓ Bright colors, split response to pattern, haptics convey activity	Additional bright color options, try different patterns, range of vibrations, Merge with happy
Happy	✓	✕ Pattern might be too close to waves	Merge with excited, offer range of colors and patterns
Calm	✓ Esp. by parents	✓ Waves and blue	Consider additional wave-like patterns, cool colors; subtler haptic cues might fit better if at all
Depressed/ Sad	✕	✕ Keep color as it works for calm and neutral	Make color an option for calm, experiment with fading color transitions; do not pursue negative valence, low arousal emotions
Afraid	✕	✕	Do not pursue, angry is a more recognizable high-arousal, negative valence emotion
Angry	✕	✓	Use rarely (e.g., to scare pets or alert), make design more confrontational with flashing lights, strong haptics

However, given we were fairly successful evoking emotions in the desired quadrants of the Circumplex model for several emotions, it is worth considering whether conveying an individual emotion might be the wrong goal. Perhaps trying to develop a set of designs, rather than a single one, that people associate with a Quadrant (e.g. 1:Positive Valence/High Arousal or 2:Positive Valence/Low Arousal) of the Circumplex would be better. For example, instead Happy or Excited specifically, designs that aim to convey Quadrant 1. As described in Table G-1, influenced by participants' desire for positive couches we emphasize iteration on designs that convey Positive Valence (emotions like Calm, Excited, Happy). However, given the success we had conveying Angry and its suggested use in some situations (e.g. during arguments, to stop abuse by pets) we plan to continue developing designs that convey Quadrant 4.